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Correlation of the Devonian sedimentary formations of North America. By G. Arthur Cooper, *Chairman* **1729–1794**

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RECONNAISSANCE SURVEY OF THE ROBERTS MOUNTAINS, NEVADA

BY C. W. MERRIAM AND C. A. ANDERSON

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ABSTRACT

The Roberts Mountains region, central Nevada, provides an excellent section of Paleozoic rocks ranging from Upper Cambrian to Permian. Major low-angle thrusting is indicated by deformed Ordovician strata resting on Paleozoics of varying age. Overlying a thick breccia zone, the upper thrust plate consists of sandstones, andesitic flows and tuffs, black shales, and bedded cherts (Vinini formation). Ordovician age of the Vinini is established on the basis of graptolite faunules. A belt of Lower to Middle Ordovician graptolitic facies similar to the Vinini formation crosses the Great Basin west of Roberts Mountains. Deposits of roughly the same age in the Roberts Mountains meridian and eastward are dominantly limestone, carrying distinct faunas. Axial planes of overturned folds in the thrust plate dip west, a further indication that the upper thrust plate moved from west to east. Minimum horizontal displacement is 16 miles. The date of thrusting is uncertain, but presumably was later Cretaceous or early Tertiary. Following thrusting, an alaskite stock and rhyolite porphyry plugs were intruded; lava flows and tuffs covered the area in part. Thrust plate and cover

of volcanics have been broken into normal fault blocks. The post-thrusting igneous rocks, like volcanic rocks of Utah and New Mexico, are characterized by high potash content.

INTRODUCTION

Among the important results of recent geologic investigation in Nevada, western Utah, and southeastern California is recognition of widespread low-angle thrust faulting. Extending our knowledge of this type of deformation to a previously little-known area, a thrust plate of great magnitude is described in the Roberts Mountains of east-central Nevada. In addition the general geology of the area is presented briefly.

For several years Merriam has studied the Paleozoic stratigraphy and paleontology of central Nevada, emphasizing the Devonian system. Sections of the Devonian and adjacent rocks were measured by instrumental survey, and reconnaissance mapping was done to show distribution of the Devonian rocks. Some of the results of detailed stratigraphic work in the eastern portion of the Roberts Mountains quadrangle have been published (Merriam, 1940).

It soon became apparent that thrusting followed by normal faulting greatly complicated the structural picture, and that igneous activity, separating the two periods of deformation, required special attention. In order to clarify the geologic history of the region Anderson joined Merriam during the summer of 1939 in a continuation of the project. Reconnaissance mapping initiated by Merriam was carried forward, and Anderson spent some time on a study of the igneous rocks. In this paper, Merriam assumes responsibility for all statements relating to Paleozoic stratigraphy and paleontology; Anderson is responsible for the igneous rocks, and both writers have joined in discussion of the structure.

The Roberts Mountains, east-central Nevada, are located in the northeast corner of the quadrangle bearing this name, and about 25 miles northwest of Eureka; less than a quarter of the quadrangle has been mapped in this study. Fifteen miles south of the Roberts Mountains is the Lincoln Highway, serving as the southern boundary of the mapped area.

The quadrangle map (scale 1/250,000) was enlarged to twice original scale for field work, and the major formations and faults have been plotted. The writers wish to express their appreciation to the topographers for an excellent base map; the enlargement was found very serviceable in reconnaissance mapping.

ACKNOWLEDGMENTS

The writers are indebted to many geologists for advice and helpful criticism. Among these, special thanks are due Dr. Sheridan A. Berthiaume

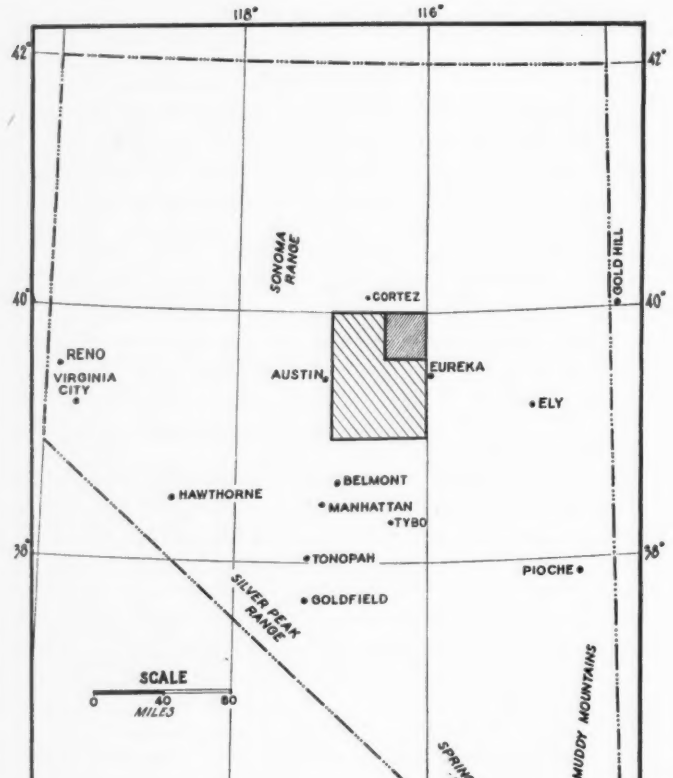

FIGURE 1.—*Index map of Nevada*

Roberts Mountains quadrangle shown in light shading; area of Plate 4 indicated by heavy shading. Localities referred to are also marked.

for help in the field. Berthiaume was investigating the Carboniferous in central Nevada and assisted in study of the later Paleozoic rocks of the Roberts Mountains region. Doctors T. B. Nolan and H. G. Ferguson of

the United States Geological Survey and Dr. S. W. Muller of Stanford University have been generous with advice, particularly valuable owing to their familiarity with the region. Special thanks are due Dr. Rudolf Ruedemann, whose graptolite identifications form a part of this study. Dr. C. M. Nevin of Cornell University and Dr. James Gilluly of the University of California obligingly read and criticized the manuscript. Grateful acknowledgment is made to The Geological Society of America for a grant from the Penrose Bequest used in support of field investigation and for chemical analyses of igneous rocks.

TOPOGRAPHY

The Roberts Mountains are roughly triangular in outline culminating in a central peak (Roberts Creek Mountain) with an elevation of 10,125 feet (Pl. 1, fig. 2). Western Peak, 4 miles northwest of Roberts Creek Mountain, rises abruptly from Denay Valley to an elevation of 9102 feet. Between Western Peak and Roberts Creek Mountain, a linear east-west ridge has two peaks each 9500 feet in elevation (Pl. 1, fig. 2); the prominent eastern eminence has been given the name Cooper Peak. Intermittent streams drain the mountain with a roughly radial pattern. One permanent stream, large for this region (Roberts Creek), flows southward from Roberts Creek Mountain (Pl. 1, fig. 1); another shorter permanent stream, Pete Hanson Creek, drains a small portion of the northwest part of the Roberts Mountains. Permanent springs are fairly numerous in the higher part of the range. The northern boundary is the broad alluviated Denay Valley, rising gently toward the southwest on the flank of a low divide separating Roberts Mountains from the Simpson Park Range. The western and southern boundaries are also alluviated forming the northern margin of Kobeh Valley. This is broken by a low ridge 6 miles long projecting south-southeast. To the east, the Roberts Mountains are separated in part from the Sulphur Spring Mountains by Garden Valley which dies out southward; the southeastern portion of the Roberts Mountains merges directly into the Sulphur Spring Mountains, interrupted by Mount Hope, an oval-shaped hill with summit elevation of 8412 feet (Pl. 2, fig. 3). The Sulphur Spring Mountains extend southward as a low north-south ridge culminating in Whistler Mountain with an elevation of 8167 feet. The alluviated margins of the Roberts and the Sulphur Spring Mountains range in elevation from 6000 to 6500 feet so that a maximum relief of 4000 feet is represented by Roberts Creek Mountain. Lone Mountain to the south of Roberts Mountains rises like an island above Kobeh Valley (Pl. 1, fig. 3); the summit with an elevation of 7940 feet is about 1800 feet above its base.

GENERAL STRATIGRAPHY

Paleozoic strata occupy the surface over some three-fourths of the Roberts Mountains area. Lavas and locally stratified tuffaceous deposits cover much of the remaining part. These extrusive igneous rocks are presumably Cenozoic. In addition several classes of post-Paleozoic intrusives have been recognized. The oldest exposed Paleozoic rocks are Upper Cambrian, while the latest beds of this era have been assigned to the Permian (Table 1). Mesozoic rocks are not known, though in the adjoining Eureka district terrestrial Cretaceous beds have been reported (Nolan, oral communication; MacNeil, 1939). Possible Triassic strata are present in the Sulphur Spring Mountains, though of such occurrence there is no confirmation (S. A. Berthiaume, oral communication). Owing to faulting and lack of outcrop a portion of the later Devonian and earlier Carboniferous does not appear at the surface in the Roberts Mountains proper but is represented in the southern portion of the mapped area at Lone Mountain and Devils Gate. Here and there on the lower alluviated slopes bordering Kobeh Valley are exposures of white sands and silts representing Pleistocene lake beds; in some localities as at Lone Mountain these contain abundant diatoms.

Two genetically distinct successions of Paleozoic sediments are recognized in the Roberts Mountains region: one regarded as the normal section, the other representing sediments of a different belt. The last owe their present location to thrust fault displacement. Strata of the thrust plate are of Lower and Middle Ordovician age, while those of the normal section extend from Upper Cambrian to Permian.

NORMAL SEQUENCE OF PALEOZOIC STRATA

GENERAL STATEMENT

The normal sequence is well exposed in the central Roberts Mountains (Pl. 1, fig. 2), at Lone Mountain (Pl. 1, fig. 3), in the Sulphur Spring Mountains, and at the southern end of the Whistler Range. In the central Roberts Mountains the section is fairly continuous from the base of the Eureka quartzite (Middle Ordovician) to the upper Nevada formation (Middle Devonian), while at Lone Mountain there appears to be no important physical break between the upper Pogonip (Chazyan) and the middle of the Devils Gate formation (higher Middle Devonian). In both sections the sedimentation is, excepting the Eureka quartzite, predominantly calcareous with minor amounts of argillaceous debris. In the Roberts Mountains the maximum unbroken section of Paleozoics is of the order of 8500 feet; at Lone Mountain the entire section exposed measures 7300 feet. The later Paleozoics are well exposed in the Sulphur

FIGURE 1. LOOKING NORTH TOWARD ROBERTS CREEK MOUNTAIN
Lava-capped mesa to right. Prominent hills in middleground center and left, Nevada limestone.

FIGURE 2. LOOKING EAST TOWARD COOPER PEAK (LEFT) AND ROBERTS CREEK MOUNTAIN (RIGHT)
Easterly dipping Paleozoic section in fault contact to the north (left) with dolomites of Cooper Peak. Prominent cliff in foreground Eureka quartzite.

FIGURE 3. LONE MOUNTAIN VIEWED FROM THE NORTHWEST
Homoclinal block of Paleozoic sediments dipping eastward (to the left), ranging from Pogonip Ordovician (right base) to Devils Gate Devonian at top of section.

ROBERTS MOUNTAINS

FIGURE 1. UNDIFFERENTIATED CARBONIFEROUS CHERT-PEBBLE CONGLOMERATES AND QUARTZITES DIPPING STEEPLY WESTWARD (OVERTURNED)
Looking north.

FIGURE 2. BEDDED UPPER VININI CHERTS WITH BLACK SHALE INTERBEDS
Exposed along Dry Creek.

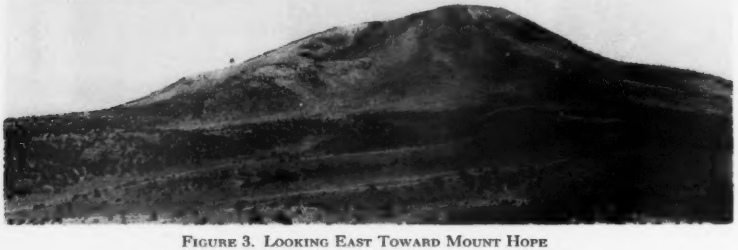

FIGURE 3. LOOKING EAST TOWARD MOUNT HOPE
Plug of rhyolite porphyry intruded in the Vinini sediments.

UNDIFFERENTIATED CARBONIFEROUS, VININI CHERTS
AND MOUNT HOPE PLUG

TABLE 1.—*Normal Section in Roberts Mountains Region*

Period		Formation	Description
PERMIAN		Undifferentiated Permian and Pennsylvanian in Sulphur Spring Mountains 5000 feet	Reddish conglomerate with limestone cobbles; chert pebble conglomerate and quartzite; lower part with sandy to pebbly limestones and fusulinid limestones
CARBONIFEROUS		(discontinuity, greater part of Diamond Peak unrecognized)	
		Diamond Peak beds	Black clay shales, brownish sandstones and conglomerates
DEVONIAN	Upper	Devils Gate formation 2065 feet	Dark-gray well-bedded limestone and calcareous shale; lower part heavily bedded or massive light- and dark-gray to black dolomitic limestones
	Middle	Nevada formation 2400 feet	Massive or heavily bedded gray and black limestones, siliceous limestones and dolomitic limestones in upper part; lower part dark-gray well-bedded shaly or argillaceous limestones
	Lower		
SILURIAN		Lone Mountain formation 2200 feet	Massive and blocky dolomites of light-gray smoke-gray and dark-gray color
		Roberts Mountains formation 1900 feet	Well-bedded dark slate-gray limestones, crystalline limestones; dark cherty limestone member at base
ORDOVICIAN	Upper	Hanson Creek formation 560 feet	Dark-gray heavily bedded limestone, thin-bedded bluish-gray limestone; dark-gray dolomitic limestone below
	Middle	Eureka quartzite 500 feet	Upper 300 feet mostly white vitreous quartzite; lower 200 feet with dark- and light-gray quartzite predominant
		(discontinuity in Roberts Mountains, Pogonip group, upper part unrecognized)	
	Lower	Pogonip group, lower part; undifferentiated Lower Ordovician and Upper Cambrian	Dark gray thin-bedded limestones; dolomites
CAMBRIAN			

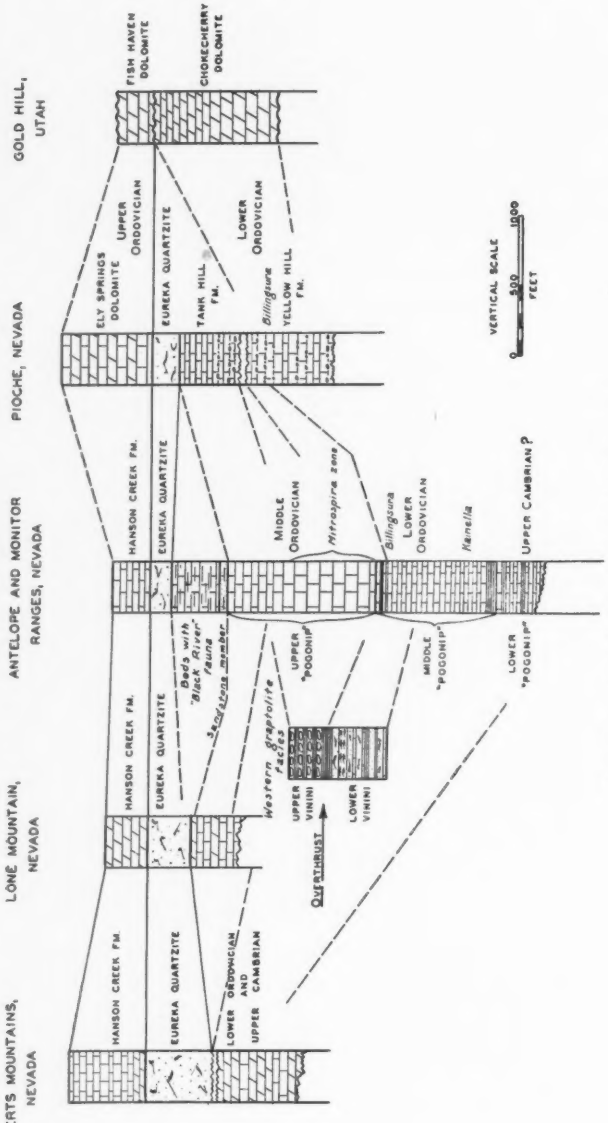

FIGURE 2.—*Correlation chart of the Ordovician*

Spring Mountains to the east, where Carboniferous and Permian lie in fault contact with older rocks. To the south in the Whistler Range and at Devils Gate are the most complete sections of higher Devonian and the only definitely known exposures of Lower Carboniferous in the area covered by the present survey.

POGONIP GROUP

The name "Pogonip limestone" has been used broadly for strata in the Great Basin lying between the base of the Eureka quartzite and the top of the Upper Cambrian Dunderberg shale (Eureka district). Following this interpretation, the "Pogonip" may embrace faunal zones ranging from Upper Cambrian to approximately Black River Middle Ordovician. Recent studies in the Antelope and Monitor ranges 35 miles south of Roberts Mountains indicate within the vertical limits of the "Pogonip limestone" in this region at least three recognizable formational units, each with distinctive faunal characterization. Walcott (1923, p. 466) proposed the name "Goodwin formation" [1] for the lower 1500 feet of the Pogonip in the Eureka district. If accepted, the term "Goodwin formation" requires more specific lithologic and faunal delimitation, for the lower 1500 feet of the Pogonip as defined by Hague includes important stratigraphic boundaries and at least two distinct faunas. In the Antelope-Monitor area (Fig. 2) the lowermost Pogonip appears to be Cambrian, while the succeeding Pogonip with *Kainella* is correlative with "Ozarkian".

Within the Roberts Mountains the Pogonip group is poorly represented. Where best developed on the west flank of Western Peak the rocks below the Eureka quartzite show little similarity to the thick Pogonip section of the Antelope and Monitor ranges 50 miles to the south. The Roberts Mountains Pogonip includes thinly bedded dark-gray limestone and dolomites showing heavier bedding. Local evidences of replacement indicate that the dolomite is in part secondary. No evidence was found of the upper Pogonip limestones which in the Monitor Range are over 1000 feet thick. Fossils collected at Western Peak within 500 feet of the Eureka quartzite appear to be Upper Cambrian. The fossils are as follows: *Eurekia* cf. *granulosa* Walcott, *Agnostus* sp., and *Acrotreta* sp. In the section on the west side of Roberts Creek Mountain Kirk (1933, p. 31) found fossils some 300 feet below the Eureka quartzite, which are "of lower Pogonip age (approximately Beekmantown) and rather early in that". As recognized by Kirk there is an apparent gap of some significance with much, perhaps the greater part, of the Pogonip group absent. Whether erosion or nondeposition is the correct explanation has

[1] The "Goodwin" bears a fauna which Walcott assigned to the "Lower Ozarkian." Ulrich and Cooper (1938, p. 24, 26) regard the "Goodwin" as Upper Ozarkian.

not been determined. Cutting out of the higher divisions of the Pogonip group either by normal faulting or thrusting does not seem possible.

The section at Cortez, 18 miles north-northwest of Roberts Creek Mountain, shows about 350 feet of Eureka quartzite underlain by roughly 1000 feet of barren dark-gray dolomites and magnesian limestones which bear little resemblance to Pogonip of the better-known sections to the south. In absence of fossils it is a reasonable assumption that all the pre-Eureka sediments represented at Cortez may be Cambrian.

The character and age of the deposits immediately below the Eureka quartzite change southward from Cortez and Roberts Mountains; at Lone Mountain Chazyan upper Pogonip limestones are found below the Eureka quartzite, while in the Antelope-Monitor area beds of approximately Black River age occur beneath the main body of quartzite, and above Chazyan upper Pogonip.

EUREKA QUARTZITE

Exposures of Eureka quartzite are found on the northwest side of Roberts Creek Mountain, on the western flank of Western Peak, and at Lone Mountain. Judging from the difference between thicknesses in the Roberts Mountains and at Lone Mountain the Eureka apparently thins toward the south; the greater decrease in the southern Antelope valley area, 20 miles south of Lone Mountain, further substantiates this.

The Eureka on the northwest side of Roberts Creek Mountain is about 500 feet thick. As noted by Kirk (1933, p. 30) the basal third is sharply differentiated from the higher portion, being much darker and occasionally showing cross-bedding. The upper 350 feet has the dense vitreous or gleaming-white character typical of the formation in many areas. Evidences of bedding are usually not recognizable in this portion of the formation. Toward the top, the formation tends to lose much of its dense, vitreous character and is terminated upward by a patchy calcareous sandstone phase (Merriam, 1940, p. 11).

At Lone Mountain the Eureka is 350 feet thick, about 150 feet less than in the Roberts Mountains. It is similar to the same unit at Roberts Creek Mountain with the lower portion in general darker than the upper, and occasionally showing cross-bedding. According to Kirk (1933, p. 30-31) some 50 feet of brownish-weathering sandy dolomite lying between the "typical uppermost Pogonip limestone" (Chazyan) and the cliff-forming Eureka apparently pertains to the latter. Kirk has suggested the possibility that these lower sandy deposits together with the darker, occasionally cross-bedded lower unit of the Eureka may be equivalent to the combined *Endoceras*-bearing sand member and overlying Black River

deposits of the Antelope and Monitor ranges (Fig. 2). According to this interpretation southward thinning of the quartzite deposits may be accounted for in part by lateral replacement of the normally arenaceous lower division of the typical Eureka by a partly calcareous facies as seen in the Antelope and Monitor ranges. No apparent lack of conformity between the Eureka and underlying strata was observed at Lone Mountain and southward in the Antelope Valley region.

Hague (1892, p. 56-58) recognized an unconformity between the Eureka and overlying "Lone Mountain limestone" (unrestricted) of the Eureka district. Evidences of denudation prior to deposition of the "Lone Mountain limestone" are cited by Hague with reference to sections in the mountains connecting the Fish Creek Range with Prospect Ridge, while in other parts of the Eureka district different horizons of the "Lone Mountain limestone" and even of the Devonian are said to lie directly upon the quartzite. However, the clearest evidence of unconformity at this position is given by Ferguson (1933, p. 20-21) for the Tybo area, 80 miles south of Eureka. Here Silurian dolomites and limestones rest upon an eroded and channeled surface of Eureka quartzite; where the quartzite is missing they lie directly on Pogonip limestone. The lower or Ordovician part of the "Lone Mountain limestone" in the older sense is not represented, possibly removed by erosion.

Within the area of the present survey no convincing physical evidence of post-Eureka stripping or channeling has been recognized, and faunal evidence is still too scanty to establish erosion or nondeposition of portions of the higher Ordovician section. In view of the nature of the lithologic change passing from the faunally barren quartzitic deposits of the Eureka to the calcareous and distinctly marine beds of the later Ordovician it seems reasonable to expect here a lost interval of some magnitude insofar as the purely marine record of the Ordovician is concerned. As no fossils have been found within the Eureka quartzite proper the possibility that it may be in part at least of continental origin has not been eliminated.

HANSON CREEK FORMATION

The Upper Ordovician Hanson Creek formation rests with probable disconformity upon the Eureka quartzite. The type section of the formation is on the northwest side of Roberts Creek Mountain and crosses the east fork of Pete Hanson Creek. Hague's (1892, p. 57) "Lone Mountain limestone" has been subdivided by Merriam (1940, p. 13) with the Hanson Creek formation representing the lower or "Trenton" portion. Thin calcareous sandstones, locally patchy, lying above the typical vitreous Eureka quartzite have been regarded as the basal member of

the Hanson Creek. Above appear dark-gray dolomitic limestones found in place 10 to 15 feet above unquestionable vitreous Eureka quartzite. The lower dolomitic division is not over 40 feet thick at the type section. The remainder of the formation is medium-gray, gray, and bluish-gray limestone most of which is fine-grained. Much of the lower half of the formation is thin-bedded and slabby or shaly limestone bearing a *Cryptolithus* fauna apparently corresponding with that listed by Hague (1892, p. 59) from the "Trenton" portion of the lower "Lone Mountain limestone" northeast of Wood Cone, Eureka district. The total thickness of Hanson Creek formation at the type section is 560 feet. It is overlain conformably by the basal chert member of the Roberts Mountains Silurian.

At Lone Mountain the Hanson Creek formation is only 318 feet thick and is largely medium- to dark-gray dolomite and dolomitic limestone. Streptelasmoid corals occur at the base, but otherwise identifiable fossils are rare. In this respect the section differs decidedly from that on Pete Hanson Creek. In the Monitor Range, 20 miles south of Lone Mountain, the Hanson Creek formation is largely well bedded flaggy limestone and calcareous shale. Here several zones throughout the formation contain graptolites. The following forms have been identified by Ruedemann from the Hanson Creek beds of the Monitor Range:

Climacograptus tridentatus Lapworth var. *maximus* Decker
Orthograptus calcaratus Lapworth var. *trifidus* Gurley
Orthograptus sp.
Dicellograptus complanatus Lapworth var. *ornatus* Lapworth

According to Ruedemann *Dicellograptus complanatus* var. *ornatus* occurs on Trail Creek in the Hailey quadrangle, Idaho, while the other species occur in the Lower Sylvan beds of Oklahoma and the Polk Creek beds in Arkansas where *Dicellograptus complanatus* also is found. Decker (1935, p. 698) considers the Sylvan to represent upper Richmond at the top of the Ordovician. Otherwise the rather large fauna of the Hanson Creek remains unstudied. In the Monitor Range the Hanson Creek beds are overlain by the Roberts Mountains formation bearing abundant *Monograptus*.

ROBERTS MOUNTAINS FORMATION

The type section of the Roberts Mountains formation lies on the west side of Roberts Creek Mountain where it is 1900 feet thick. The lower member is a siliceous limestone, with lenses and interbeds of bluish-black chert. This cherty zone is very persistent in central Nevada. The upper limit of the formation is the base of light-gray dolomites of the Lone Mountain formation (restricted). The Roberts Mountains formation or its equivalents formed part of the original "Lone Mountain limestone" of

Hague. At the type section the formation consists largely of dark slate-gray limestones with only a moderate amount of dolomite. This contrasts sharply with the overlying Lone Mountain formation (restricted) which is almost entirely dolomitic. Much of the formation exhibits slabby or flaggy parting. The lower and medial portions include many crinoidal beds. In the upper 800 feet the bedding tends to become more massive, while the upper 220 feet of the formation is partly dolomitic. The relationship with the overlying Lone Mountain formation is apparently gradational. Fossils are numerous throughout the Roberts Mountains formation. Most characteristic are pentameroid brachiopods of the genus *Conchidium* or *Virgiana*. Corals are abundant with *Halysites*, Heliolitidae, favositids, and small solitary rugose forms within the lower 300 feet. Many horizons throughout the remainder of the formation have yielded excellent coral assemblages, including Heliolitidae, many forms of tabulates, and several compound Rugosa which suggest *Strombodes*.

At Lone Mountain the Roberts Mountains formation, including the basal chert member, is only 741 feet thick and largely dolomitic. Fossils are relatively rare. In the Monitor Range the Roberts Mountains interval is represented by the basal cherty limestone succession and overlying well-bedded limestones.

Two species of *Monograptus* have been identified by Ruedemann from a horizon a short distance above the cherty member in the Monitor Range; *Monograptus acus* Lapworth and *Monograptus pandus* Lapworth. According to Ruedemann (written communication)

> "*Monograptus acus* was already known to the writer from the Trail Creek beds in the Hailey quadrangle, Idaho; *M. pandus* had already been listed by me from the Brisco limestone in British Columbia and was further observed in collections from Galena Creek, tributary of Prairie River, N. W. T. Also two varieties are noted here from Trail Creek."

As pointed out by Ruedemann *M. acus* is listed by Elles and Wood from British zones 23 and 24 and *M. pandus* from zones 22, 23, and 24. On this basis the lowermost zone of the Roberts Mountains formation which yielded the graptolites is "of the approximate age of the lower and middle Gala beds of Great Britain, or of Clinton (and younger age) of New York."

In the higher beds of the Monitor Range a large and well-preserved Silurian fauna has been found; this assemblage appears to represent a facies quite different from any recognized in the Roberts Mountains. A few of the corals of the type section of the Roberts Mountains formation have been recognized in the Monitor Silurian strata and also at Ikes Canyon in the Toquima Range. Evidently Silurian strata older than the Lone Mountain formation (restricted) are widespread in central Nevada.

LONE MOUNTAIN FORMATION (RESTRICTED)

The name Lone Mountain formation has been redefined and restricted by Merriam (1940, p. 13). The "Lone Mountain limestone" of Hague (1892, p. 57) included that part of the Paleozoic section at Lone Mountain and in the Eureka district lying between the Eureka quartzite and the Nevada limestone of Devonian age. In the original usage the formation included at least three definable lithologic units and embraced Upper Ordovician, Silurian, and possibly Lower Devonian strata. At the type section the Lone Mountain as restricted is 1570 feet thick, while in the Roberts Mountains it increases to 2200 feet. The formation consists of light mouse-gray and darker smoky-gray dolomites and dolomitic limestones usually weathering to light mouse gray. Bedding is generally obscure or massive, and the outcrop surfaces are frequently blocky. At many points the contact relationship of the Lone Mountain with the underlying Roberts Mountains Silurian and with the overlying Nevada limestone of Devonian age appears to be gradational. At Lone Mountain the basal contact is within a zone where the dolomites change from the predominantly dark gray of the Roberts Mountains formation to lighter grays of the higher Silurian dolomites. On the west side of Roberts Creek Mountain a bed of smoke-gray crinoidal dolomite with crinoid stems half an inch in diameter lies near the base of the Lone Mountain formation.

Below the main body of the Nevada formation in the Roberts Mountains and in the Sulphur Spring Mountains a zone of dolomitic limestone bearing a distinctive Lower Devonian fauna is found. *Spirifer* cf. *arenosa* is common. Though sometimes similar lithologically to the Lone Mountain dolomite these deposits are on a faunal basis referred to the Nevada as a basal member.

Other than a questionable *Syringopora* found near the base of the unit at Lone Mountain no determinable fossils have been obtained from the Lone Mountain formation. However, the age is reasonably well fixed by overlying and underlying formations as Upper Silurian with the possibility that some portion of the early Devonian may also be represented. A study of the large faunas from the Roberts Mountains formation at the type locality and Monitor Range should place more exact limitations on the age of the Lone Mountain, in view of Lower Devonian assignment of the overlying beds with *Spirifer* cf. *arenosa*.

NEVADA FORMATION (RESTRICTED)

The term Nevada formation has been redefined (Merriam, 1940, p. 14) to apply only to the lower part of the "Nevada limestone" of Hague (1892, p. 63). Merriam designated the upper portion of the original "Nevada

limestone" as Devils Gate formation. The type section of the Nevada formation as redefined lies at Modoc Peak in the western part of the original Eureka sheet (Hague, 1892). The formation is calcareous throughout and largely limestone, but in the upper 600 feet, as at Lone Mountain, many dolomitic members occur.

The subzone bearing *Spirifer* cf. *arenosa* is included with the Nevada formation as its basal division; lithologically it is sometimes similar to the underlying Lone Mountain. Above the lower division 500 to 700 feet of the Nevada may be distinguished by lithology from the higher members. In general this portion is inclined to be dark gray, thinly bedded, with argillaceous or shaly partings, and rich in fossils. The upper two-thirds of the formation is more heavily bedded and includes siliceous limestones and dolomites. In general the upper members are sparingly fossiliferous as compared with the lower, though certain zones in the silicified portion (*Martinia kirki* zone) yield silicified fossils in abundance, while toward the top of the formation deposits of stromatoporoid limestone and *Cladopora* limestone are common. The uppermost members of the Nevada fall in the *Stringocephalus* zone. Deposits of this zone are frequently medium-gray to dark-gray and black dolomites or magnesian limestones. These beds often contain abundant fragmentary silicified shells of *Stringocephalus*. The upper limit of the Nevada formation (restricted) is established at the top of the highest bed containing *Stringocephalus* in view of the abundance, broad geographic distribution, and limited vertical range of this important brachiopod genus. The Nevada formation has been subdivided (Merriam, 1940, p. 9) into four major paleontologic zones with a number of subzones and horizons recognized on fossil evidence. The major zones are as follows from bottom to top: (1) *Spirifer kobehana* zone; *Spirifer pinyonensis* zone; (3) *Martinia kirki* zone; (4) *Stringocephalus* zone.

In the Roberts Mountains the highest Nevada beds recognized belong in the *Martinia kirki* zone, for the uppermost Nevada or *Stringocephalus* zone and the Devils Gate formation apparently were cut out by faulting or occupy brecciated belts within which stratigraphic determination is not possible. The section at Lone Mountain is probably the best in central Nevada for study of the Nevada formation. In the Sulphur Spring Mountains on the eastern border, the lower Nevada is well exposed. Here are the best-known occurrences of the Lower Devonian *Spirifer* cf. *arenosa* beds which lie immediately east of a major normal fault separating Permian or Upper Carboniferous sediments from those of Lower Devonian and upper Lone Mountain (Silurian) age.

DEVILS GATE FORMATION

In redefining and subdividing the "Nevada limestone" of Hague the Devonian beds of central Nevada which lie above the *Stringocephalus* zone were designated as the Devils Gate formation (Merriam, 1940, p. 16). The type section is at Devils Gate where about 1100 feet of dark-gray limestones and subordinate calcareous shales is exposed. Only about half the formation is exposed at Devils Gate. However, to the south and east along Modoc Ridge lower and lower strata appear until at Modoc Peak (original Eureka sheet) an 1800-foot sequence of the Devils Gate formation reveals the basal members. At this point the upper 265 feet is not exposed. The total thickness of the Devils Gate in the type area is 2065 feet. The upper limit is marked by disappearance of the *Cyrtospirifer* or "*Spirifer disjunctus*" fauna, and the dark, bluish-gray, highly calcareous shales pass into platy, black, and usually noncalcareous shales of the Diamond Peak Carboniferous. The lower 900 feet consists largely of thick-bedded, light-gray, and very dark-gray dolomites and dolomitic limestones including numerous members filled with stromatoporoids and *Cladopora*. Other organic remains are rare in this portion of the section. The upper part of the formation as exposed at Devils Gate is largely limestone and much more fossiliferous, particularly the uppermost 800 feet. Within the upper 100 feet occurs a bed of edgewise limestone conglomerate showing angular and flat fragments of dark laminated limestone in a matrix of lighter argillaceous lime. The abundant fossils in this bed seem to occur almost entirely in the darker reworked fragments and not in the matrix.

The Devils Gate has been subdivided faunally (Merriam, 1940, p. 9) into three zones, from top to bottom as follows: (1) *Cyrtospirifer* zone; (2) *Phillipsastraea* zone; (3) *Spirifer argentarius* zone. The lowest fossiliferous beds of the *Spirifer argentarius* zone recognized lie from 800 to 900 feet above the base, defined by the highest known occurrence of *Stringocephalus*.

Distribution of the Devils Gate formation is very limited within the area of the present survey. Other than the type section the only known outcrop is at Lone Mountain where the lower 1100 feet is exposed. In the Roberts Mountains these beds appear to have been cut out by faulting or so badly brecciated as to be unrecognizable.

DIAMOND PEAK BEDS

Lower Carboniferous strata representing the Diamond Peak are found only in a small area at Devils Gate, resting upon the *Cyrtospirifer* beds of the Devils Gate Devonian. The deposits are dark, usually noncalcareous shales with interbedded thin, impure quartzitic layers and occasional

lenses of fine pebble conglomerate. A sill of alaskite porphyry has invaded the contact zone of the Devils Gate and Diamond Peak where these strata are best exposed on the north side of Devils Gate pass. In this vicinity the overthrust Vinini black shales are also present. When graptolites are absent it has been found difficult to separate these Ordovician deposits from the Diamond Peak beds which resemble them lithologically.

The best sections of the Diamond Peak beds are found at Diamond Peak and Newark Mountain on the east side of the Eureka district. Here the black Lower Carboniferous shales at the base are separated from the Devils Gate Devonian by a black crinoidal limestone, probably pertaining to the former.

While no true Diamond Peak beds have been recognized with certainty in the Roberts Mountains it is possible that a few small black shale areas here mapped as Vinini Ordovician and others included with undifferentiated Paleozoic, may represent windows of this Carboniferous division.

The term Diamond Peak beds is employed to include not only the original "Diamond Peak quartzite" of Diamond Peak (Eureka district) but in addition the underlying black shales and sandy interbeds referred by Hague (1892, p. 156-157) to the "White Pine shale". Actually the "Diamond Peak quartzite" includes a very large percentage of conglomerate at Diamond Peak, and the lithologic term is misleading. As the stratigraphic relations of the true White Pine formation in the White Pine district are not well understood it appears undesirable to use this term for dark shales of the Eureka and Roberts Mountains areas.

UNDIFFERENTIATED CARBONIFEROUS AND PERMIAN

A belt of Carboniferous and Permian rocks outcrops conspicuously in the western portion of the Sulphur Spring Mountains. Standing nearly vertical the resistant conglomerate and quartzites of this succession produce a line of strike ridges which may be followed for more than 16 miles. The ridges are particularly prominent north and south of the mouth of Tyrone Creek. In their southern extension these rocks generally dip eastward at very high angles; in the middle part the beds are locally overturned, dipping steeply to the west (Pl. 2, fig. 1). The Carboniferous and Permian rocks are in fault contact on both east and west sides of the belt. On the east a major fault brings the lower Nevada and the Lone Mountain dolomite into contact with Permian for a distance of 11 miles. While to westward the Ordovician Vinini is normally faulted against Carboniferous, it appears likely that the Vinini was previously thrust over these younger rocks. The later normal faults are assumed to cut the thrust plate giving the present visible relationship (Pl. 4).

The lowest Carboniferous beds exposed are limestones which have yielded a fusulinid faunule. Certain of the limestones in this portion of the section are argillaceous, showing mud cracks. Above this facies sand grains and pebbles are admixed with the limestone, and the bedding is frequently characterized by cross-lamination. The ridge-forming conglomerates follow. Within this portion of the section at least two recognizable subdivisions were found: (1) a lower very resistant chert pebble conglomerate including some interbeds of sandstone or quartzite; (2) a higher conglomerate containing many limestone cobbles and pebbles. In the upper conglomerate the cementing material is commonly red; red sandy and silty lenses are present, particularly near the top of the succession. Locally the lower or chert pebble conglomerate shows evidence of post-depositional silicification and sometimes appears almost homogeneous, with occasional faint outlines of the original chert pebbles. At present no attempt is made to subdivide these rocks on a paleontologic basis.[2] However, the lowest fusulinid limestones are in all probability Pennsylvanian, while the later reddish conglomerates and silts are regarded as Permian.

DOLOMITES OF COOPER PEAK

The east-west trending ridge culminating in Cooper Peak consists of fractured, veined, and altered limestones and dolomites (Merriam, 1940, p. 35). Little evidence of bedding is visible, and the eastern portion of the dolomite is similar to that of the Lone Mountain formation. Two and a half miles west of Cooper Peak a large and well-preserved fauna of silicified brachiopods and corals was found in badly fractured unstratified dolomitic limestone. The assemblage, including *Trematospira cooperi* and *Spirifer* cf. *arenosa*, is Lower Devonian. In the Sulphur Spring Mountains this fauna occurs below the shaly division of the Nevada limestone and below the range of several fossil forms characteristic of the upper *Spirifer kobehana* zone. The dolomite is separated from underlying formations by a low-angle thrust fault dipping to the west. The fault is well defined 350 feet below the summit of Cooper Peak. Directly below the thrust fault to the east and north of Cooper Peak lower and middle Nevada limestones dip about 45° to the southwest with middle Nevada below the lower Nevada indicating overturning of beds beneath the thrust. At other points north and northwest of Cooper Peak evidence of overturning of lower Nevada beds below the thrust plane was found. Probably the dolomites of the Cooper Peak mass

[2] Dr. S. A. Berthiaume has completed a detailed study of the Carboniferous and Permian rocks of the Roberts Mountains region, the Eureka district, and the Diamond Range. Presentation of the results of stratigraphic investigation in the Sulphur Spring Mountains is therefore not attempted in this reconnaissance study.

include much disturbed rocks ranging from pre-Lone Mountain Silurian to lower Nevada Devonian.

UNDIFFERENTIATED PALEOZOIC ROCKS

An area of dark shales along Jackass Creek north of the conspicuous Nevada limestone window shows lithologic features suggesting that it may not pertain to the Vinini overthrust plate. In spite of lithologic similarity to the Vinini no graptolites were found, and the sediments contain abundant peculiar subcylindrical bodies several inches long which have somewhat the appearance of badly preserved plant (lycopod) stems. Whether these pieces are actually organic or wholly concretionary has not been determined. Possibly this is a window exposing sediments as late as Carboniferous. While the occurrence of Diamond Peak Lower Carboniferous black shale beneath the overriding thrust plate has not clearly been demonstrated, it is probable that it exists here.

ROCKS OF ROBERTS MOUNTAINS THRUST PLATE

GENERAL STATEMENT

Lower and Middle Ordovician strata differing lithologically and faunally from the calcareous Ordovician rocks of the normal section outcrop over a wider area in the Roberts Mountains than those of any other Paleozoic division. They represent a plate thrust at a low angle over the underlying rocks. Since there are excellent exposures and good fossil localities along Vinini Creek the name Vinini formation has been applied to these strata.

Rocks of the Vinini formation have been traced from McClusky Pass on the west to the Sulphur Spring Mountains on the east, a distance of 20 miles. In a north-south direction the outcrop of Vinini extends practically unbroken from the mouth of Dry Creek to the region east of Yahoo Canyon in the Eureka district, a distance of 30 miles. Outliers and erosion remnants indicate a former more extended distribution.

The Vinini formation actually embraces at least two and possibly three formational divisions. Owing to complexities of structure and small scale of the base map it has not been feasible to cartographically illustrate a subdivision. When large-scale maps are available the Vinini can probably be separated into units which will bring out many features of the structure not dealt with in this report. For the present two divisions, lower Vinini and upper Vinini, are recognized.

The exposed normal section does not appear to include stratigraphic equivalents of the Vinini formation in the Roberts Mountains, owing to absence of the upper, and probably much of the middle, Pogonip as a result of pre-Eureka erosion or nondeposition. In the Antelope and Moni-

tor ranges, however, the Pogonip includes probable stratigraphic but not facies or faunal equivalents of the entire Vinini formation (Fig. 2).

LOWER VININI

General statement.—Lower strata of the Vinini formation are best exposed on the east side of Roberts Creek Mountain, along the main east fork of Vinini Creek. The deposits here consist of dark-gray, brownish-weathering bedded quartzites, gray arenaceous limestones or calcareous sandstones commonly showing cross-lamination, and fine laminated sandy and brownish-gray and greenish-brown silty sediments. Locally the silty beds have a shaly parting, and in some localities true black shales are present in the lower Vinini. Within the lower Vinini no attempt has been made to work out in detail the vertical order of various subsidiary lithologic units owing to the folding and overturning of these beds.

Lava flows and tuffs.—Near the top of the lower Vinini, lava flows and tuffs occur at several localities. These are particularly well shown about 3 miles south of Roberts Creek Mountain just east of Roberts Creek. Here 40 feet of tuff-breccia grades upward into several feet of greenish volcanic sand overlain by cherty shale, typical of the upper Vinini. Nearby an amygdaloidal lava flow about 40 feet thick is exposed, also overlain by cherty shale of the upper Vinini. At two other localities, only amygdaloidal lava was observed, such as the outcrop previously noted along Vinini Creek and on the west flank of Roberts Creek Mountain 4 miles east of the mouth of Jackass Creek. The lava flow along Roberts Creek has numerous thin tabular calcic andesine phenocrysts imbedded in a finely crystalline groundmass of albite microlites, slender iron oxide needles presumably pseudomorphic after amphibole, rare chlorite crystals, and epidote granules. Secondary calcite is present both as amygdaloidal fillings and veinlets. In the other exposures of lava, the plagioclase phenocrysts consist of turbid albite, in part replaced by calcite, associated with a groundmass of albite microlites, chlorite flakes, and iron-ore granules. In some amygdules, fibrous chlorite surrounds a calcite core. One specimen of lava contains no feldspar phenocrysts, but pseudomorphs of chlorite and granular quartz preserve the outlines of former hornblende phenocrysts. The matrix of the tuff-breccia contains large and small lithic fragments similar to the lavas described above. Crystal fragments are very turbid albite and aggregates of chlorite frequently spherulitic. Calcite and granular quartz are the cementing material. The tuffs and lavas presumably were hornblende andesites that have been chloritized, and, with the exception of the lava flow containing andesine phenocrysts, extensive albitization has taken place.

Turner (1902) reported, in the Silver Peak Range, 170 miles to the south-southwest, rhyolitic and dacitic tuffs and lavas interbedded with dark cherts of the Palmetto group, which is also Ordovician. However, the Palmetto igneous rocks are said to be interbedded with "Normanskill" cherts and therefore on the whole may postdate the Vinini extrusives occurring at the top of the lower Vinini of Deepkill or Beekmantown age, and below the upper Vinini cherts. Igneous rocks have not definitely been found within the main body of upper Vinini cherts which probably correlate roughly with the Normanskill Palmetto cherts.

Age of lower Vinini.—Among the abundant graptolites of the lower Vinini on Vinini Creek, Ruedemann has recognized the following forms:

Dictyonema n. sp.
Tetragraptus similis (Hall)
T. quadribrachiatus (Hall)
Phyllograptus cf. *angustifolius* (Hall)
Didymograptus nitidus (Hall)
Isograptus gibberulus Nicholson (*Didymograptus caduceus* Salter)
Cardiograptus folium Ruedemann

In addition small orthoid brachiopods and the trilobite *Pliomerops* occur in sandy or quartzitic layers immediately above the graptolite faunule listed. Hexactinellid sponge spicules are very abundant in certain graptolite beds.

Ruedemann regards the graptolite assemblage as clearly of the same age as the *Tetragraptus* beds of the lower Deepkill shale in New York State, or of lower Canadian (Beekmantown) age. The fauna is also well represented in the Ordovician of Idaho and British Columbia. Of particular interest is the Australian genus *Cardiograptus* found also in the Idaho and British Columbia faunules.

Several additional graptolite localities have been found in the lower Vinini on both the east and the west side of the Roberts Mountains as well as the central part of the range. In some places the graptolites occur in quartzitic beds as well as in the silty and shaly deposits. Judging from diversity of the graptolite faunules at these localities probably several graptolite horizons are represented within the lower Vinini.

UPPER VININI

General statement.—A succession of bedded cherts and black organic shales constitutes the upper Vinini which follows the lavas and tuffs of the lower division. In most sections studied the chert beds and lenses make up more of the thickness than the shale interbeds, though at certain exposures only the shale was recognized. Except where the resistant cherts are exposed, outcrops of this unit are often poor (Pl. 3, fig. 3).

The chert layers generally vary in thickness from 1 to 4 inches (Pl. 2, fig. 2), while the organic shale partings are frequently less than 1 inch thick. In spite of the black color of the organic shale and the black to dark-gray and greenish color of much of the chert when fresh, both shale and chert tend to weather limonite brown, cream, white, and grayish white. From a distance, whitish outcrops of upper Vinini may be mistaken for tuff. Along Vinini Creek and at other localities throughout the Roberts Mountains region the shales are readily ignited. The oil yield on distillation of selected samples is above 25 gallons per ton. Where the black shale interbeds have a high content of bituminous matter, the dark chert layers probably carry much of the same.

Within the shale interbeds rounded or walnut-shaped nodules are common. These sometimes consist of a combination of siliceous and bituminous material with some calcium carbonate and often much pyrite. The nodules resemble small coal balls and on sectioning reveal well-preserved organic remains (Merriam and Daugherty, 1938). The shales and particularly the nodules are highly graptolitic, also bearing large quantities of Radiolaria, and microscopic algae. The highly bituminous or oil-bearing shale facies is apparently limited to the central and eastern Roberts Mountains belt, extending from the Vinini Creek drainage southward to Devils Gate.

Upper Vinini cherts.—The siliceous strata are clearly not the result of silicification of earlier sediments but are original primary bedded cherts, separated by thin shale partings. The chalcedonic cherts are pale green to black, with layers ranging from 1 to 4 inches in thickness, a few reaching 1 foot or more. On a fresh moistened fracture surface, clear round areas can be detected with a hand lens, resembling outlines of Radiolaria such as characterize cherts of the Jurassic Franciscan formation in the Coast Ranges of California. Under the microscope, these areas appear as clear minute aggregates of quartz or chalcedony, the latter arranged in spherulitic fibers, similar to the Radiolaria as described by Davis (1918, p. 257) in the Franciscan cherts. In some, the chalcedonic fibers are surrounded by microgranular quartz. The clear areas are surrounded by cryptocrystalline silica which polarizes feebly. In the gray to black cherts, dark-brown isotropic spots are visible in thin section. These resemble organic matter (bituminous?) such as that which characterizes some Miocene cherts of the Coast Range in California (Davis, 1918, p. 288). Quartz veinlets are common in the cherts representing minute fracture lines later sealed with quartz.

FIGURE 1. EAST SIDE OF ROBERTS CREEK MOUNTAIN
Illustrating crags (middleground) of eroded, brecciated base of upper thrust plate. White crag to right is composed of Nevada (?) limestone. Foreground shows rocks of Vinini formation.

FIGURE 2. BRECCIA ZONE AT BASE OF THRUST PLATE
East slope of Roberts Creek Mountain.

FIGURE 3. WINDOW OF NEVADA LIMESTONE (BACKGROUND) PROJECTING THROUGH OVERTHRUST VININI
Southeast of Jackass Creek. Rounded topography in foreground characteristic of much of the Vinini.

ROBERTS MOUNTAINS THRUST PLATE

The occurrence of chert above lava as noted on Vinini Creek is interesting in view of the suggestion that the siliceous sediments owe their origin directly or indirectly to volcanic activity (Taliaferro, 1933). In this connection attention is called to the work of Ruedemann and Wilson (1936) who have suggested a relationship between the widespread occurrence of Normanskill radiolarian cherts in eastern North America and an episode of igneous activity. The petrographic character and manner of occurrence of the New York Normanskill cherts is quite similar to the upper Vinini with, in both cases, association of cherts and the pure type of graptolite shale (Ruedemann, 1935). However, in the eastern New York area chert is most abundant in the lower part of the Normanskill, while the upper Vinini appears to represent upper Normanskill.

Age of upper Vinini.—From black organic shales of this division the following graptolite species have been identified by Ruedemann:

Leptograptus flaccidus (Hall) var. *spinifer* Elles and Wood mut. *trentonensis* Ruedemann
Dicranograptus spinifer Lapworth
Diplograptus angustifolius (Hall)
Orthograptus calcaratus var. *acutus* Lapworth
Climacograptus bicornis (Hall), narrow variety
C. modestus Ruedemann
Retiograptus geinitzianus (Hall)

In addition to graptolites, the upper Vinini beds contain abundant Radiolaria, thin-shelled protremate brachiopods, and microscopic protophycean algae (Merriam and Daugherty, 1938). Ruedemann has concluded that this faunule is of upper Normanskill age and identical with faunules from Bruno Creek, Bay Horse quadrangle, Idaho, Fall Creek, Hailey quadrangle, Idaho, and British Columbia. Typical *Dicranograptus spinifer* as found in the Vinini shale has not been observed in eastern North America but occurs in the Idaho localities here mentioned.

Garden Pass (Summit) graptolite zone.—An important graptolite faunule was collected at Garden Pass (Summit), Nevada, by Walcott (Gurley, 1896, p. 302). This assemblage, one of the first found in western America, occurs on the old right of way of the defunct Eureka and Nevada railroad where it traverses the low pass separating the Roberts Mountains block from the Sulphur Spring Mountains. The exact association has not been recognized elsewhere in the Vinini formation and probably represents a zone between that of the lower Vinini and the upper Vinini organic shales and cherts. On a paleontologic basis it is therefore likely that at least a three-fold subdivision of the Vinini formation is possible with a time range from lower Canadian to upper Chazyan. The long interval of Ordovician time involved emphasizes

the possible thickness of these highly dislocated and eroded overthrust rocks.

Graptolites collected by Walcott (Gurley, 1896, p. 302) "at the crossing of the Eureka and Palisade Railroad at Summit, Nevada," have been identified by Lapworth, Gurley, and Ruedemann. The forms listed by Gurley are as follows:

Dendrograptus cf. *serpens* Hopkinson
Didymograptus perflexus Gurley
Phyllograptus sp. indet.
Diplograptus sp.
Climacograptus caelatus
Cryptograptus tricornis
Glossograptus ciliatus
Thamnograptus anna

Ruedemann regards the form referred to *Glossograptus ciliatus* by Lapworth (manuscript report) and by Gurley (1896) as a "mutation" of this species which he described as *Glossograptus ciliatus* mutation *horridus*. According to Ruedemann (1908, p. 384) the following forms are associated at the Garden Pass (Summit) locality:

Glossograptus ciliatus mutation *horridus*
Phyllograptus anna
Climacograptus caelatus
Cryptograptus tricornis
Caryocaris

On the basis of this assemblage the deposits at Garden Pass (Summit) have been regarded by Ruedemann as probably Upper Beekmantown.

Whether the graptolite specimens collected by Walcott and identified by Lapworth and Gurley were all obtained from exactly the same zone is not known. The possibility that they represent more than one zone must be considered in view of structural complexity in these shaly deposits at Garden Pass (Summit). The graptolitic deposits in this region are known to include several clearly defined divisions. As listed the Garden Pass (Summit) faunule is distinct from those recognized on Vinini Creek and at other localities throughout the mountain area, appearing on paleontologic grounds to require a stratigraphic position between the lower Vinini and upper Vinini assemblages.

Because of profound dislocation of the Vinini formation it has not been possible to obtain reliable figures for thickness of the two divisions. However, on Vinini Creek the combined thickness remaining probably cannot be less than 500 feet, and much of this section has certainly been removed by erosion. Black graptolitic shales and cherts at the north end of the Simpson Park Range west of McClusky Pass appear to represent only the upper Vinini and may greatly exceed the figure given for this division alone.

FACIES CHANGE IN LOWER AND MIDDLE ORDOVICIAN

GENERAL STATEMENT

West of the Roberts Mountains throughout a broad belt extending 170 miles south-southwest from the Simpson Park Mountains and Toquima Range to the Silver Peak Mountains of western Nevada, marked and complex facies changes are to be expected in rocks of Lower and Middle Ordovician (Pogonip) age. Kirk (1933, p. 29) in his description of the Eureka quartzite notes that west of the 117th meridian "The Middle Ordovician is represented largely by graptolite shales with minor amounts of sandstones, limestones, and calcareous shaly beds". The 117th meridian is the western border of the Roberts Mountains quadrangle but lies 30 miles west of the Roberts Mountains proper. All available data indicate that east of this variable belt the deposits of Canadian (Beekmantown) and Chazyan age are predominantly marine limestones or dolomites with subordinate arenaceous and argillaceous facies. Westward the known Lower and Middle Ordovician includes a high percentage of argillaceous and arenaceous strata with a notable amount of graptolitic shale and chert. With respect to the Roberts Mountains and the Antelope-Monitor area the terms western and eastern facies may conveniently be employed in a general sense.

EASTERN FACIES

Deposits of the eastern facies are not well shown in the Roberts Mountains proper where, as discussed above, only the lower part of the Pogonip has been recognized. However, in the same meridional belt at Lone Mountain and in the Antelope-Monitor area 20 miles south of this locality, typical representation of the eastern facies is found. While the Lone Mountain exposures show only the upper or Chazyan portion to advantage, the Antelope Monitor sections below the Eureka quartzite include some 2300 feet of strata extending from Early Ordovician or "Ozarkian" to the Middle Ordovician Black River beds (Fig. 2). In these more southerly sections limestone predominates, with subordinate fine sandy and argillaceous deposits. No Vinini-type rocks or faunas are known to occur in the normal stratigraphic sequence.

WESTERN FACIES

A great development of black graptolitic shales and cherts is found in the Simpson Park Range adjoining the Roberts Mountains on the west, but it is not known whether these represent a westward extension of the Roberts Mountains upper thrust plate or are part of an unthrust sequence.

West of Potts in the poorly known northern part of the Toquima Range true graptolite shales of Ordovician age have not been identified, though graptolites occur sparingly here in the Pogonip limestones and abundantly in adjacent Silurian calcareous beds. In the southern part of this range, however, the Ordovician section includes much argillaceous and arenaceous sediment, suggesting partial replacement of the Pogonip limestones by these clastic facies.

Graptolite shales have long been known at Belmont, some 85 miles south-southwest of Roberts Mountains on the eastern margin of the Toquima Range (Gilbert, 1875, p. 180). At this locality the beds have been subjected to varying degrees of metamorphism. In the Manhattan district near the south end of the Toquima Range and at Belmont, Ferguson (1924, p. 20-25) has described the Ordovician Toquima formation. The division is commonly marked by a basal quartzite which nowhere exceeds 50 feet and in places is lacking. Above this are dark slates with Normanskill graptolites. Below the Toquima formation are schists, schistose slates, and limestones which on a basis of lithologic similarity to beds above the Normanskill graptolites are tentatively assigned to the Ordovician. Above the graptolitic slate of the Toquima is a gray limestone with jaspilite identical with the limestone below the Toquima. While above the Toquima limestones no constant succession of beds could be recognized, the bulk of superjacent Toquima apparently consists of chloritic schist with beds of dark siliceous slate or chert and a few intercalations of crystalline limestone. Interbedded and interfingering quartzite and graptolitic slate are also found within the complex but in uncertain position. Broadly speaking, lithologic similarity to the Vinini formation is noteworthy, though no detailed comparison is yet possible.

In the Silver Peak Range, 170 miles south-southwest of Roberts Mountains, Turner (1902) described the Palmetto formation as consisting of dark thin-bedded cherts with layers of gray graptolite shales, smaller amounts of reddish slates, and occasional limestone layers. Two graptolite horizons occur, the lower containing graptolites of Beekmantown age and the higher with a Normanskill faunule. Reported igneous rocks associated with the cherts have been discussed above. Again there exists a similarity to the Vinini formation.

Fifty miles west of Roberts Mountains in the Toyabe Range, Emmons (1870, p. 324) noted a quartzite series overlain by slates "which included fissile limestone shales, more or less siliceous clay-slates, and locally, schistose and somewhat crystalline rocks, resembling mica and hornblende schists, and in one instance, a marbleized limestone." Spurr (1903, p. 94-95) has suggested that these slates are probably the same

as the slates of the Toquima Range to the south, and on the basis of graptolites found in that range by Gilbert (1875, p. 180) the rocks in the Toyabe Range were dated by Spurr as lower Silurian (Ordovician in the present usage). These strata have been intruded by granites and have undergone some metamorphism, thus differing from the Vinini formation. The same situation has been recognized in the Toquima Range (Ferguson, 1924, p. 38) where the Ordovician rocks are intensely folded and locally metamorphosed.

Correlation of the western graptolitic rocks with the normal Pogonip section in the Antelope-Monitor region is unsatisfactory. However, the upper Vinini with its Normanskill graptolite faunas probably represents some portion of the Chazyan upper Pogonip interval (Fig. 2), though a correlation with the superjacent "Black River" beds is conceivable. The lower Vinini with Deepkill graptolite faunas probably falls within the limits of the Canadian portion of the Pogonip near the zone carrying *Billingsura*. Occurrence of *Phyllograptus* cf. *loringi* in the *Billingsura* zone (Kirk, 1934, p. 455) of the Antelope Range is significant.

Though information concerning Lower and Middle Ordovician rocks in western Nevada is scanty,[3] all facts point to the existence of one or perhaps several more or less lineal marine belts or subordinate troughs in which graptolitic facies are prominent. The belts apparently extended north-northeast across the Great Basin from the Silver Peak area, communicating with central Idaho where correlative graptolitic beds are found. Faunal evidence further suggests a connection with British Columbia. Comparison with conditions in the restricted Ordovician faunal belts of the Appalachian geosyncline may be fruitful at a later date.

ROBERTS MOUNTAINS THRUST

GENERAL STATEMENT

In terms of structural geology the most striking feature of the Roberts Mountains is a very extensive low-angle thrust resulting in discordant position of Vinini Ordovician strata on Paleozoic rocks of varying age. Independent minor thrusts are also recognizable. Breaking of a local fold has been suggested to explain the origin of that beneath the Cooper Peak dolomite mass.

Some of the smaller folds in this area are intimately related to the major thrusting, while the broad major flexures are older, though pos-

[3] Additional thick exposures of western facies Ordovician are known in the southwestern part of the Hawthorne quadrangle, Miller Mountain and Candelaria Hills, and northern part of the Sonoma Range quadrangle (H. G. Ferguson, personal communication).

sibly pertaining to an earlier phase of the same diastrophic episode. In general the folds of the Roberts Mountains region are of four types: (1) broad flexures affecting Paleozoic rocks below the thrust surface; (2) isoclinal folds within the major thrust plate; (3) minor irregular folds within the major thrust plate; (4) minor drag folds associated with normal faults.

On limbs of the broad flexures the strata vary in strike from north-south to northwest or northeast, while observed dips range from 25° to over 50°, with overturning in exceptional cases. At Lone Mountain and Roberts Creek Mountain there is a gradual but on the whole marked increase in dip within the same section passing from the lower (Ordovician) to the higher (Devonian) strata (Merriam, 1940, p. 19, 33). The broad folds have been extensively eroded and usually appear only as homoclines (Lone Mountain) which represent but a portion of one limb. Closure is rarely encountered in these structures. Where crests or keels may exist much fracturing and minor faulting is to be expected, and the beds rarely carry over from one limb to another in continuity.

Isoclinal folding is recognized locally and is inferred to be very common within the thrust sheet. Widespread minor irregular folds in the thrust sheet resulted, like the isoclinal folds, from forces causing the thrust movement. Axes of the irregular folds vary greatly and were probably controlled to a large extent by irregularities in the surface over which the thrust sheet moved. Overturning is common.

The more important normal faults and fault zones within the mountain mass are of two different sets with respect to direction: those which trend from north-northwest to slightly east of north, and those extending transversely in more or less an east-west direction. Displacement on faults of the first set may exceed 6000 feet as on Pete Hanson Creek where upper Nevada has been carried downward in contact with Eureka quartzite and older rocks. Most of the normal faults recognized are later than the major thrusting.

EVIDENCE OF MAJOR THRUSTING

Evidence for the thrust is greatly strengthened by occurrence of Ordovician graptolites at numerous scattered localities (Pl. 4). Resemblance of the lower Vinini with dark quartzitic members to the Carboniferous Diamond Peak beds was at first highly confusing. In the absence of faunal evidence at the outset of this study it seemed a natural conclusion that these deformed strata were younger than the Nevada Devonian, merely representing local thrust plates.

Mapping brings out lack of accordance of the Vinini formation to structure of the underlying rocks. Where the base of the thrust plate

is exposed, it is usually marked by a very pronounced breccia zone, at least 30 to 40 feet thick (Pl. 3, figs. 1, 2). These breccias are best developed where the cherty layers of the upper Vinini have been fragmented. On the east slope of Roberts Creek Mountain near the summit area, chert-breccias grade upward into bedded cherts. Thin sections of the chert-breccias reveal radiolarian tests in the fragments with no recrystallization of the cryptocrystalline base. They are strongly cemented by quartz. The resistant thrust breccias are often silicified and stained by iron oxide so that they outcrop locally as brownish-black crags. No slickensided surfaces were found at the base of the thrust plate or in the underlying rocks. A revealing exposure near the summit area of Roberts Creek Mountain shows an intimate mixture of chert and limestone fragments at the base with "dikes" of breccia 4 feet wide and 12 feet long injected in massive limestone. In other exposures, near the summit, chert-breccia from the overlying Vinini rests upon limestone-breccia derived from the underlying Nevada formation.

The thrust surface is highly irregular with windows of underlying rocks now exposed by erosion (Pl. 3, fig. 3). Most windows which yielded fossils are of the Nevada formation. On the eastern flank of Roberts Creek Mountain the fault surface dips eastward from 5° to 20°. On the western flank of the mountain, the surface is inclined to the west at a moderate angle, but no exposures give an exact measure of the dip.

The Vinini beds are unmetamorphosed but have been intensely folded and crumpled with strikes ranging from N. 30° W. to N. 40° E.; in the main these trends appear to average about N. 10° W. The dips are also variable but in general range from 30° to 50°. In spite of moderate dips, overturning is often observed, the axial planes dipping west. An exception to this can be seen around Whistler Mountain where vertical dips and isoclinal folds are common. Possibly the muscovite alaskite stock comprising Whistler Mountain caused this local tight folding by pushing aside the Vinini formation at the time of intrusion.

DIRECTION OF MOVEMENT

In the following discussion, the term "direction of movement" of the upper thrust plate is used in a relative sense with no implication that only the upper block moved. It is believed that much more mapping must be done in the surrounding region before sufficient evidence is available to suggest whether "overthrusting" or "underthrusting" dominated.

Dip of the thrust surface does not indicate direction of movement, for both east and west dips are widespread (Pl. 4). Inclination of axial planes in small overturned folds within the Vinini is probably more significant, as in most instances the axial planes were found to dip westward.

Eastward movement of the Vinini plate is therefore indicated; this necessarily presupposes development of the small folds at the time of thrusting.

Perhaps the most convincing evidence for eastward movement is seen in distribution and facies relations of Great Basin Ordovician deposits. Rocks and faunas of the Vinini formation are totally unlike those of normal Pogonip in the eastern facies, showing on the other hand decided similarity to Ordovician of the western belt. Strata of the upper plate are not, therefore, thought to be of local origin but to have moved from the west where the Ordovician is known to include variable sediments with predominant graptolitic facies.

No conclusive evidence regarding total movement of the upper plate is available. However, in the Roberts Mountains the Vinini thrust rocks are exposed almost continuously for an east-west width of 16 miles (Pl. 4), giving this minimum value of horizontal displacement. Undoubtedly the true horizontal movement is much greater. Whether the black graptolitic shales and cherts of the adjoining Simpson Park Range to the west have also undergone horizontal displacement is not known.

Determination of actual thrust magnitude must await more detailed lateral tracing of the two distinct Ordovician facies. So far, data on intergradation or rate of change from western to eastern facies are lacking. The possibility that the two were in no way directly connected at the time of deposition must also be considered. As pointed out by Ferguson (personal communication), the eastern facies at Tybo, Hot Creek Range, is only about 25 miles in an air line from the western facies at Belmont, Toquima Range. In absence of evidence for horizontal movement between these two points, the distance seems short for such complete change in lithology.

Whereas it would be premature to comment extensively upon the relation of the Roberts Mountains thrust to other known major thrusts in Nevada and adjoining regions, it is significant that several of these give evidence of eastward movement. In the nearby Eureka district Nolan (personal communication) recognizes important thrusting with displacement in this direction. Among those more remote is the Muddy Mountains thrust (Longwell, 1922) some 260 miles south-southeast, where the upper plate moved from the southwest. Thrusts described by Glock (1929), Nolan (1929), and Hewett (1931) in the Spring Mountains west of the Muddy Mountains show relative eastward movement of the overlying block.

STRUCTURAL HISTORY

In unraveling the complex structural history, the following suggestions are made. It has been assumed that the Paleozoic rocks in normal

sequence at Western Peak, Roberts Creek Mountain, and Lone Mountain represent limbs of folds (Pl. 4); only by this type of deformation is it possible to account for the high angles of dip shown by these tilted blocks. The same assumption is made for the Carboniferous and Permian rocks in the Sulphur Spring Mountains as well as Devonian strata to the east. Folding would also partly explain the distribution of the Middle Devonian Nevada formation, which appears as windows through the upper thrust plate (Pl. 4). During or following movements responsible for these folds three different kinds of faults developed. Several transverse faults have caused offsets in the Paleozoic rocks between Western Peak and Roberts Creek Mountain (Pl. 4). Associated with these is a minor low-angle thrust separating the dolomites of Cooper Peak from underlying Paleozoics. This subordinate thrust plate is apparently of local origin, made up of brecciated and dolomitized lower Nevada, probably Lone Mountain, and perhaps older rocks. Displacement of the upper plate from west to east is suggested by westerly dip of the thrust plane and by drag and overturning in Nevada limestone below the thrust sole at Cooper Peak. Apparently after the Cooper Peak thrust formed, normal faulting down-dropped Nevada limestone to the west and southwest of Roberts Creek Mountain (Pl. 4).

Following initial folding and local faulting the main Roberts Mountains upper thrust plate appears to have moved eastward, carried along by competent beds now eroded away, while the somewhat incompetent Vinini acted as the sole of the thrust sheet. A major fault of this nature might be expected to cut folds of the underlying rocks, producing a relatively regular and uniform thrust surface. On the contrary, small isolated windows of Nevada limestone (Pl. 3, fig. 3) now projecting through the eroded thrust plate indicate that the thrust surface is quite irregular. Most of the Nevada windows appear too small and too steep-walled to be explained wholly by later warping or faulting, but give the impression of having been prominences or monadnocks rising above a pre-thrusting topographic surface of relatively low relief. Under present conditions of erosion the Nevada limestone is quite resistant as compared to associated rocks.

While no positive evidence for movement of the Vinini plate over an erosion surface is forthcoming, the highly irregular features of the thrust surface described above might be expected under these conditions. In this connection mention of reported surface thrusting in Nevada and Utah may be significant. In the Muddy Mountains Longwell (1926, p. 570) found coarse conglomerate at the base of a thrust plate with pebbles and cobbles derived from the thrust plate itself filling depressions in the under-

lying Jurassic sandstone. Many of the pebbles have been sliced repeatedly by shearing, and nearly all were crushed. Muller and Ferguson (1939, p. 1618) describe similar features in the Hawthorne and Tonopah quadrangles, Nevada, while Nolan (1935, p. 57) suggested that a thrust in the Gold Hill district, Utah, moved over an erosion surface.

After thrusting considerable erosion took place, so that no measure of the original thrust plate thickness can now be given. A cycle of igneous activity ensued, followed by normal faulting which resulted in dislocation of the thrust sheet and its local cover of volcanics (Pl. 4). Warping or folding of the thrust plate preceding later normal faulting cannot be wholly excluded. However, apparent lack of coincidence of the many irregularities on the thrust surface with structures in underlying rock suggests that subsequent warping may not be a major factor.

Dating of the structural events is unsatisfactory in absence of adequate post-Paleozoic stratigraphic evidence within the limits of this study. In the Great Basin and surrounding regions where thrusts are becoming widely recognized the geographic limits of Nevadan (late Jurassic) and Laramide (late Cretaceous) influence are not fully understood; possibility of both earlier and later compressional diastrophism must also be entertained.

Within the area under consideration the youngest rocks involved in the major folding are undifferentiated Carboniferous and Permian. Ordovician rocks make up the entire upper thrust plate, and the youngest strata definitely covered by the thrust plate are of Devils Gate (Upper Devonian) age. Probably the undifferentiated Carboniferous and Permian in the Sulphur Spring Mountains were covered by the thrust, but at present all outcrops of these are separated from the thrust sheet by normal faults. Hence the only positive evidence is that the folding is later than rocks regarded as Permian and may thus be post-Paleozoic. The major thrusting followed folding, with perhaps no great time interval separating the two events.

Further speculations are of necessity based on analogy with thrusting in other areas. Nolan (personal communication) in the near-by Eureka mining district finds fresh-water Cretaceous involved in eastward thrust movement, thus providing a possible lower limit for corresponding events in the surrounding territory.[4] Assuming a middle or upper Tertiary age for the post-thrusting volcanics of the Roberts Mountains, it is therefore suggested that the major thrusting in question took place either in later Cretaceous or early Tertiary time.

[4] According to Nolan (personal communication) the fresh-water Cretaceous of the Eureka district may have been deposited during later phases of the thrusting.

POST-THRUSTING IGNEOUS ROCKS

GENERAL STATEMENT

After the widespread thrusting of the Vinini formation and the subsequent erosion, a cycle of igneous activity began. In Whistler Mountain, a stock of alaskite and sill offshoots have intruded the Vinini as well as later Paleozoic formations. No evidence is available to place these intrusives in the known igneous sequence which began with the intrusion of rhyolite porphyry plugs. Contemporaneous with or following the intrusion of the plugs, rhyolitic tuffs and breccias containing porphyry fragments filled canyons cut into the thrust plate. These fragmental deposits were covered by sheets of andesitic lava. Somewhat similar andesite dikes are abundant in the basement, particularly in the Paleozoic limestones, and these possibly served as feeders for the lava flows. In the northeastern corner of the Roberts Mountains, quartz latite plugs and lava flows piled up an impressive volcanic field. This activity was followed by erosion, for quartz latite fragments in clastic deposits north of Garden Valley are overlain by olivine basalt flows. A late andesite flow also covers the quartz latite in one area.

ALASKITE STOCK AND ALASKITE PORPHYRY SILLS

The largest intrusive body in the Roberts Mountains area exposed on Whistler Mountain is a muscovite alaskite stock 6 miles long and 2 miles wide. The elongation is roughly parallel to the strikes of the shales and cherts of the nearby Vinini formation. The isoclinal folding in the Vinini formation may indicate that the alaskite stock made way for itself largely by pushing and thrusting aside the country rock. No frozen inclusions of country rock were found which might favor stoping. Metamorphic effects on the Vinini formation are slight. The shales appear more indurated, but no recrystallization was recognized in thin section even in specimens collected near the contact. Gray limestones also show no indication of recrystallization.

The alaskite is rather fine-grained and holocrystalline; quartz, feldspar, and muscovite can be recognized with the lens. Some sporadic biotite is present. The petrographic details are discussed in a later section. The alaskite resembles aplite, but thin sections reveal a hypidiomorphic texture rather than the typical allotriomorphic texture of aplites, and for this reason the rock has been termed an alaskite. Directly south of the main peak, the stock contains locally spherical and ellipsoidal tourmaline nodules as much as 2 inches in diameter. Most of these nodules consist of tourmaline and quartz, thin sections revealing that the tourmaline has replaced the feldspar and mica, but in a

few the center is composed of random fibers of pure tourmaline in which even the quartz has been replaced.

At the south end of the stock, sills of fine-grained alaskite and muscovite alaskite porphyry parallel the Paleozoic rocks immediately north of Devils Gate. These sills have intruded the Devils Gate limestones (Upper Devonian) and a sequence of quartzites and black spheroidal shales which may represent the Diamond Peak Carboniferous. No metamorphism is recognizable, and even the shales show little indication of induration. At least four and possibly more sills are present, but owing to complications of later faulting the exact sequence was not worked out. The sills range from 20 to 50 feet in thickness, and they possess a rude columnar jointing as well as platy jointing parallel to the sill contacts.

The rocks composing the sills are light gray to white, and some of the sills are aphyric with a fine crystalline texture. Other sills are porphyritic with scattered smoky quartz, dull feldspar, and brilliant muscovite phenocrysts imbedded in a finely crystalline groundmass. In all the sills, iron and manganese oxide stains permeate the rocks and coat the joints so that it is impossible to obtain specimens free from this secondary coating.

Since these sills have the same mineral assemblage and are close to the alaskite stock, clearly they represent offshoots from the main stock and must have been intruded at or about the same time. Unfortunately, all that can be stated concerning the age of intrusion is that it is post-thrusting. If the thrusting took place in the late Cretaceous or early Tertiary, the alaskite intrusions must be Tertiary, but no statement can be based on direct evidence. The general north-northwest alignment of the several intrusives—alaskite stock, porphyry plugs, and quartz latite domes—possibly suggests a structural control and general contemporaneity. A comparable stock of quartz monzonite has been reported by Nolan (1935, p. 43-48) in the Gold Hill district as Eocene or Oligocene, so that the alaskite may be early Tertiary. But no evidence contradicts middle Tertiary age.

RHYOLITE PORPHYRY PLUGS AND DIKES

Three large and three small plugs of porphyry have been mapped in the present study. In addition narrow dikes of similar rock were found chiefly in the region of Garden Pass, but the map scale prohibits their representation. The most southerly of these plugs comprises Mount Hope (Pl. 2, fig. 3). In addition to the main plug, small dike offshoots occur at several places on the lower slopes of Mount Hope. Fresh samples of the Mount Hope intrusive are difficult to obtain for the

feldspar phenocrysts are dull and chalky, and the rock has a gray dull luster. Occasional fresh samples are brilliant white with numerous scattered round and corroded smoky quartz phenocrysts associated with pale-cream colored sanidine phenocrysts. Plagioclase and mafic minerals are absent. The groundmass is very finely crystalline. The chemical analysis indicates that this plug is composed of potash rhyolite porphyry. It was reported to the writers that the Mount Hope porphyry plug has been mineralized with sphalerite and galena, and abandoned mine workings are located at the southeastern margin of the plug. Undoubtedly this mineralization is responsible for the altered appearance of most of the intrusive. The dikes in the Garden Pass region are also potash rhyolite porphyry.

The plugs to the northwest of Mount Hope are similar except that the quartz phenocrysts are usually more smoky, and plagioclase is an important constituent along with sanidine. Also scattered small crystals of biotite and reddish garnet appear against the grayish-white finely crystalline groundmass. The unusual appearance of this garnet is characteristic of these intrusives and is of some importance in relating these intrusives to the later igneous history, as will be emphasized later. Zirkel (1876, p. 195) recognized this garnet in a specimen from this region in connection with the Fortieth Parallel studies. The two largest plugs are 2 miles northwest of Mount Hope, and, in addition to intruding the Vinini formation, one has penetrated a window of Nevada limestone. A small plug occurs on the south slope of Vinini Creek Canyon also northwest of Mount Hope, and two are present on the eastern slope of Roberts Creek Mountain 2 and 2½ miles respectively southeast of the summit.

TUFFS AND BRECCIAS

The next episode in the geologic history is represented by deposits of rhyolite tuff and breccia which filled a canyon or canyons cut in the Roberts Mountains thrust plate. The thickest accumulation of these deposits is 4 miles south-southwest of Roberts Creek Mountain where 700 feet of tuffs and breccias appear beneath the lava cap. They thin rapidly to the north and south so that, at the northern edge of the largest lava mesa, only a few feet of breccia separates the Vinini from the lava cap. As a rule, exposures of the tuff are poor, for the overlying lava tends to slide or to break into talus covering the tuff. In the thick section of tuff, scattered exposures give a general sequence as follows: Above the Vinini formation is a thick deposit of white massive pumice lapilli tuff in which quartz, sanidine, and plagioclase crystals are prominent. Above this is a breccia of the garnet-bearing por-

phyry with complete absence of glass or pumice fragments. The fragments of porphyry in the breccia vary in size up to 1 foot or more in diameter. Overlying the porphyry-breccia is a thick layer of grayish coarse vitric-crystal tuff, according to the nomenclature of Wentworth and Williams (1932, p. 52). This particular tuff is well indurated, and thin sections reveal recrystallization of the glass shards indicating some incipient welding during or shortly after emplacement. The remainder of the visible section consists of pink, massive pumice-lapilli vitric-crystal tuff in which large quartz, sanidine, plagioclase, and biotite crystals are distinct. The crystals are of the same size and character as those in the garnet-bearing porphyry plugs; however, no garnet was observed in the tuff. On the north side of the large lava mesa, scattered fragments of garnet-bearing porphyry indicate the presence of porphyry-breccia directly under the lava, but the thickness could not be determined.

In the belt of tuff 2 to 3 miles north and northeast of Roberts Creek Ranch, 200 feet of tuff is present with the base not exposed. The exposures are very poor, but several reveal that the tuff is partly stratified and sorted, indicating water transportation. The southern margin of the andesite cap rests on the Vinini formation. North of Vinini Creek, 20 feet of fine water-laid vitric tuff rests on the Vinini formation and is in turn covered by the andesite lava cap. Two miles west and southwest of Roberts Creek Mountain, a block of andesite has been downfaulted, and tuff is poorly exposed at the margins of the andesite. At the southern end of the lava cap, 40 feet of white vitric-crystal tuff similar to that described above is exposed beneath a thin layer of porphyry-breccia. Indeed, around the margins of several of the andesite caps, scattered angular fragments of the garnet-bearing porphyry indicate the widespread distribution of this breccia prior to the outpouring of the andesite flows. Because of the purity of these breccias, undoubtedly the plugs were intruded at the same time as the tuff and breccia series accumulated, and porphyry intrusives must have reached the surface as domes. Avalanching and rapid erosion of these domes would supply the angular fragments of porphyry in great abundance and purity needed to form these breccia sheets. If the porphyry had been uncovered by erosion, fragments of the cover rock would certainly be present in the breccia. Therefore it is suggested that the garnet-bearing plugs were protruded to the surface as domes contemporaneously with explosive eruptions of rhyolitic ejecta. Some of the ejecta was later reworked by running water, accounting for the stratified and sorted tuffs. It is quite possible that the massive pumice-lapilli vitric-crystal tuffs represent the products of pelean blasts, for otherwise the tuffs would be better sorted and stratified.

The tuff deposits, particularly the stratified and sorted tuffs, are younger than the thrusting, and fossils may be found permitting the dating of this igneous cycle. In the water-laid tuffs northeast of Roberts Creek Ranch fragmentary plant stems, leaves, and indeterminate silicified coniferous woods were found.

ANDESITE FLOWS AND DIKES

Reference has already been made to the andesite which appears as isolated lava caps (Pl. 1, fig. 1) on the eastern and southern slopes of Roberts Creek Mountain as well as in a downfaulted block west of the mountain. Undoubtedly these flows were formerly much more extensive, and only erosional remnants remain. The thickest section of andesite is 4 miles southeast of Roberts Creek Mountain, where 200 feet of lava is exposed. At least four flows are present, each flow marked by a vesicular top and massive interior. The flows range from 40 to 60 feet thick. Although there are some variations in appearance, vesicular phases being rather black and dull, these flows are usually medium gray and finely crystalline. Phenocrysts are rare. Vesicles are spotted with cristobalite crystals, and irregular cavities lined with projecting crystals of feldspar are in turn coated with small spheroidal-shaped crystals of cristobalite. In the lava cap 2½ miles southeast of Roberts Creek Mountain, only two flows remain, and elsewhere on the eastern slope of Roberts Mountain only one flow can be found. In the block southwest of Roberts Creek Mountain, two or more flows are probably present, but owing to the local landslides at the margin of the flows the number was not certainly determined.

As the rhyolitic tuffs and porphyry-breccia filled canyons cut largely in the Vinini formation, and all the andesite flows have some of this material underlying them, probably the lava closely followed the rhyolitic ejections and poured down the upper portions of these valleys. Whether or not they completely filled the canyons and spread out over the entire surface cannot be answered owing to the subsequent erosion, but the limitation of these flows to areas covered with rhyolite tuffs indicates that the lava did not completely bury the region.

On the western slopes of Roberts Creek Mountain a number of andesite dikes cut the Paleozoic limestones. They are of variable width ranging up to 40 feet and are essentially vertical. Five similar dikes were noted north and east of Cooper Peak, one cutting the Vinini formation. With this one exception, all dikes noted were in limestones, but considering the methods of mapping possibly they were missed in the Vinini because of the appreciable mantle burying the dike outcrops. Even in the limestones, the dikes are appreciably weathered and usually outcrop in gaps

in the ridges. As a result of weathering, the andesite is deeply impregnated with iron oxide so that fresh samples are difficult to obtain. The andesite dikes are slightly more crystalline than the andesite in the lava flows and contain no cristobalite in cavities, but otherwise they have essentially the same texture and mineral composition. For these reasons they are probably essentially contemporaneous, and the dikes possibly represent feeding dikes for the flows.

QUARTZ LATITE FLOWS

The northeastern corner of the Roberts Mountains is covered by thick flows of quartz latite, and several patches lie to the north of Vinini Creek. Also two isolated domes appear near Roberts Creek Mountain, the larger less than 1 mile to the north and the smaller 1½ miles to the southeast. East of Dry Creek, near the western margin of the quartz latite, 75 feet of massive greenish-gray vitric-crystal quartz latite tuff underlies a friable gray quartz latite flow. Apparently the first eruptions of quartz latite, at least locally, were explosive. In the reconnaissance studies, no other exposures of tuff were located, and, if it is widely distributed, it has been covered by the extensive quartz latite flows. Doubtless detailed mapping will disclose other exposures.

The bulk of the quartz latite is pink to reddish owing to the hematite in the groundmass. The groundmass is usually aphanitic, and flow banding may be present. Locally some of the quartz latite is dark gray with a perlitic glassy groundmass. Everywhere it is in contact with the reddish quartz latite, the perlitic variety is the older, suggesting that it was the first quartz latite lava erupted.

Apparently many vents served as sources for the quartz latite lava. Many of the summit areas in the lava field have the characters of domes only slightly modified by erosion, such as the domelike shape and flow banding which is parallel to the margin of the dome and dips inward on all sides. In addition, one dome contains an appreciable amount of quartz latite breccia, apparently formed as the solid quartz latite was forced upward. These characters are common to other domes (Williams, 1932, p. 144-5). Local areas of quartz latite in the domes have been bleached white as if by solfataric action, also a common feature among recent domes. Much quartz latite represents thick viscous flows that may have poured out of these vents prior to the dome formation; in part the domes represent the last upward protrusion of lava too viscous to flow. A comparable case has been described in a recent flow elsewhere (Anderson, 1933, p. 491). Some of the domes may represent crater infillings, after the eruption of the lava flows.

Two miles northwest of Oak, a thin layer of porphyry breccia is as-

sumed because of the scattered fragments in the mantle. Directly above these fragments, a flow of andesite similar to that found to the south and southwest is directly covered by the quartz latite, thus giving positive evidence of the sequence: tuff, andesite, quartz latite.

POST-QUARTZ LATITE VOLCANIC ACTIVITY

Near the northeastern margin of the Roberts Mountains, a single flow of dark-gray pyroxene andesite makes up the summit of a small hill. It is surrounded and underlain by quartz latite, showing that it is of post-quartz latite age. In the field, this late andesite somewhat resembles the andesites of pre-quartz latite age to the south, but in thin sections it is entirely different. Obviously it is an erosional remnant, but the source vent and its original distribution are unknown. Since the quartz latite apparently did not undergo much erosion, this late andesite may have been a flow of local source and limited distribution.

The southern end of a small north-south fault block ends at the northern end of Garden Valley, and in the eroded fault scarp, which bounds the western edge of the block, poorly stratified tuff contains angular fragments of quartz latite. Olivine basalt overlies the tuff beds and makes up the eastern back slope of the fault block. The quartz latite fragments in the tuff indicate that the olivine basalt is post-quartz latite.

OTHER VOLCANIC ROCKS

At the western margin of the Roberts Mountains are two areas of volcanic rocks, but their relationship to the other volcanic rocks is unknown. The more northerly outcrops are reddish porphyritic hornblende andesite, totally different from the andesites on the eastern portion of the mountain. It resembles andesites in the Simpson Park Mountains, west of Roberts Mountains.

Two small hills of rhyolite rise above the alluvium west of the mouth of Rutabaga Creek. Only about 40 feet of rhyolite remains. At the base of the northwestern hill, a few feet of hard well-cemented rhyolite breccia is exposed beneath massive rhyolite, suggesting that the rhyolite represents a flow rather than an intrusive body. Phenocrysts of smoky quartz, plagioclase, sanidine, and biotite recall the garnet-bearing porphyry plugs, although no garnet was observed in these rocks. However, some of the tuff beneath the older andesite flows has similar crystals, and perhaps this rhyolite at the southwest margin of the Roberts Mountains is related to the rhyolite tuff series.

AGE OF THE IGNEOUS ROCKS

No evidence is available to date the igneous rocks except that they are later than the thrusting, and if this event is of late Cretaceous or early

Tertiary age the igneous rocks are necessarily Tertiary. Indeed most geologists would suggest a Tertiary age solely on the basis of comparable rocks elsewhere in Nevada that have been dated by means of fossiliferous continental beds. However, since lithologic similarity is dangerous for correlation of lavas and intrusive rocks from one district to another, the precise age of the igneous rocks in the Roberts Mountains is an open question. However, in summary the following sequence should be emphasized: (1) Rhyolite tuffs and breccias are contemporaneous with the protrusion of porphyry plugs and (2) intrusion of dikes followed by andesite flows, (3) quartz latite, and (4) later pyroxene andesite and olivine basalt. The alaskite stock and its sill offshoots, and the hornblende andesite and rhyolite on the western flank of Roberts Mountains, cannot be placed accurately in the sequence.

POSTVOLCANIC FAULTING

The andesite flows in the Roberts Mountains give evidence of the character and magnitude of the faulting which followed their eruption. Southwest of Roberts Creek Mountain, a narrow block of lava and underlying Vinini has been downfaulted against the Vinini formation on the west and Paleozoic sequence on the east. Projecting the lava westward from the exposures on the south-eastern flank of Roberts Creek Mountain to the south end of the narrow block, a net displacement on intervening faults is roughly 1500 feet. The andesite surface rises to the northwest some 800 feet in elevation, and the net displacement is probably correspondingly less. Apparently the eastern fault of this block followed a pre-existing fault causing the downdropping of the Nevada limestone prior to thrusting. Transverse faults terminate this central fault block at both the northern and southern ends. At least two other blocks have been downdropped south-southeast of Roberts Creek Mountain, and here also the andesite flows indicate the displacement. At least a 1000-foot displacement is represented in the small block 4 miles north of Roberts Creek Ranch, and a 400-foot displacement separates this block from the adjoining southwest block.

The thrust plate has been downfaulted against the undifferentiated Carboniferous rocks at the west margin of the Sulphur Spring Mountains, and probably the normal faults between the Vinini and Carboniferous rocks developed at the same time as the normal faulting of the thrust plate to the west.

OUTLINE OF ROBERTS MOUNTAINS BLOCK

Geologists today commonly assume that many of the present mountain ranges in Nevada represent fault blocks with variations, their out-

line determined largely by boundary normal faults. Apparently the age of the faulting varies, for with some ranges slightly eroded fault scarps are characteristic, and with others well-developed pediments indicate considerable recession of the original fault scarp. The Roberts Mountains and neighboring Sulphur Spring Mountains with their extension to Whistler Mountain do not have a simple outline that one can easily relate to boundary faults, so that the presence of faults where steep slopes rise above alluvium is sometimes doubtful. The eastern margin of the Sulphur Spring Mountains, although somewhat irregular, is in general sharply set off from Diamond Valley, and on physiographic evidence presumably the western margin of Diamond Valley is bounded by a normal fault. Hot springs along this margin are further suggestive evidence. However, the outline of the range is irregular, particularly in the southern extension. Where the Vinini formation makes up the southern extension, a wide pediment is present, for occasional gullies show that the alluvium represents only a rather thin veneer resting on a surface cut on the Vinini. Where the alaskite stock appears, the pediment is much narrower. It is suggested that as the rocks of the Vinini formation are intensely jointed, they are rather susceptible to mechanical disintegration in the desert environment so that the original fault scarp has been rapidly eroded back with the simultaneous development of a pediment. In the main, the alaskite has joints much more widely spaced and is slowly attacked by weathering so that the pediment to the east of the alaskite stock is developed solely in the Vinini. This relation between width of pediment and bedrock character has been emphasized by Gilluly (1937, p. 329). A suggestion of renewed faulting with uplift of the pediment surface is faint 1 mile east of the alaskite. If the small scarp, 20 feet high and somewhat eroded, gives the location of the original boundary fault, the pediment is about 1 mile wide east of the alaskite and 2 miles wide east of the ridge of Vinini formation. Farther north, the Nevada limestones apparently have receded but little except locally.

At the western margin of the Roberts Mountains is a well-developed pediment particularly from Roberts Creek Ranch to Jackass Creek. This pediment is broken by a north-south fault which passes through the Three Bar Ranch. The evidence for faulting is entirely physiographic; the pediment surface, veneered by alluvium, is cut off to the west by a north-south scarp 75 to 100 feet high. Possibly this scarp represents the location of an original boundary fault.

The northern boundary of the Roberts Mountains is rather straight and steep with exception of the northwestern area where the Vinini forma-

tion is exposed, and here a well-developed pediment is present. Physiographic evidence suggests that the northern boundary is a normal fault, but, owing to the character of the rock, little recession of the scarp has taken place.

Southeast of Roberts Creek Ranch a ridge capped by lava apparently represents a block bounded by faults on both sides—faults that are extensions of the faults in the Roberts Mountains that bound downdropped blocks. For this reason, it is possible that the internal faults in the range bordering downdropped blocks formed at the same time as the boundary faults outlining the Roberts Mountains and Sulphur Spring Mountains.

That there has been some recent faulting east of Roberts Mountains is indicated by a scarp that cuts the alluvium south of Oak in Garden Valley. The scarp is over 100 feet high 3 miles south of Oak and can be traced for about 4 miles. The alluvium appears to have been washed down the eastern slopes of Roberts Mountains and carried to the north by Henderson Creek. Garden Valley probably has a structural origin, but later detailed work may modify this suggestion.

The origin of isolated Lone Mountain, surrounded by alluvium, presents an interesting problem. It may represent a block bounded by normal faults, but no supporting evidence was found. More likely it was an area of some relief on a downfaulted block in the formation of Kobeh Valley. The base of Lone Mountain is in part composed of white diatomaceous siltstones resembling lacustrine sediments. These beds have been dissected by numerous gullies and are veneered with fanglomerate washed down from Lone Mountain. A Pleistocene lake in the Kobeh Valley is indicated by Meinzer (1917, Fig. 1) as well as one in Diamond Valley to the east. As an intermittent stream now drains Kobeh Valley into Diamond Valley through Devils Gate, probably the two Pleistocene lakes were connected, and part of the deepening of Devils Gate probably was the result of overflow. With the lowering of the outlet and disappearance of the lake, the sediments deposited in the Pleistocene lake would be eroded to their present form. The blanket of Pleistocene sediments around Lone Mountain effectively masks the base so that its origin must remain doubtful.

PETROGRAPHY OF IGNEOUS ROCKS

GENERAL STATEMENT

Details concerning the petrography of the post-thrusting igneous rocks are considered separately in order to emphasize the relations and differences among the several groups. The descriptions of the Ordovician igneous rocks, given earlier, are not here elaborated as they differ markedly from the later rocks.

ALASKITE AND ALASKITE PORPHYRY

The alaskite is fine-grained hypidiomorphic granular. The feldspar consists of sodic oligoclase and orthoclase, both somewhat clouded. The oligoclase is in small euhedral to subhedral crystals (.15 mm) with faint to sharp albite twinning. The orthoclase is usually anhedral with a few subhedral grains. The fine grain and clouded appearance make it difficult to estimate closely the ratio of plagioclase to orthoclase; the oligoclase appears to be in excess. The feldspars together account for about 66 per cent of the rock. Quartz is commonly in slightly larger grains (.2 mm), molded about the smaller oligoclase crystals. A few quartz grains poikilitically enclose oligoclase. The quartz content is approximately 32 per cent, as measured by a micrometer stage, and the normative quartz is about the same (Table 2, no. 4). The remaining 2 per cent consists largely of anhedral muscovite up to .3 mm long, molded about the other minerals, in places completely enclosing both the quartz and feldspar. Biotite, partly altered to chlorite, is rare in some specimens, either intergrown with muscovite or in minute anhedral crystals. Zircon and magnetite are minor accessory minerals. The border phase of the alaskite is very fine-grained (0.07 to .08 mm.) with the above minerals in the same proportions; no tendency toward a porphyritic texture is visible.

The tourmaline nodules mentioned earlier consist largely of tourmaline and quartz. In a few of the larger nodules, the core is composed of randomly oriented acicular crystals of black tourmaline, with an outer zone a quarter of an inch thick consisting of quartz and tourmaline. In some nodules minor amounts of feldspar may be observed in thin section. The edges of the nodules are irregular but sharp. Doubtless the tourmaline has developed largely by the replacement of the feldspar, and such remnants of feldspar as are still preserved are usually oligoclase, indicating that the orthoclase is more readily replaced. Around one nodule, muscovite interstitial to the quartz is abundant and presumably developed by replacement of feldspar. Under low magnification the quartz grains in the nodules are obviously larger and more numerous than in the enclosing alaskite. This is in keeping with the suggestion of Edwards (1936) that orthoclase plus boron yields tourmaline and quartz. Edwards in a study of comparable nodules was able to recognize later deposits of quartz. None were observed in this study, but the larger size of the quartz grains indicates addition.

The tourmaline is usually in irregular short crystals interstitial to the quartz; distinct prisms were rarely observed. In a few examples neighboring grains extinguished simultaneously, indicating a common orientation and presumably representing a poikiloblastic texture. The tourma-

line is pleochroic from medium blue to pale gray. The indices of refraction are $\varepsilon = 1.638 \pm .003$, $\omega = 1.670 \pm .005$. These indices, birefringence, and color indicate the variety schorlite, suggesting that iron as well as boron must have been added in order to develop the tourmaline.

No observations contradict Edwards' suggestion (1936) that these nodules develop by pneumatolytic replacement of feldspar *in situ* after the intrusion of the host rock. Tilley (1919) has pictured the development of bubbles of mineralizers which rose in the viscous magma until they reached the crystal mesh of quartz and feldspar and attached themselves to these crystals, attacking the feldspars and converting them into tourmaline at the same time that they deposited the excess silica as secondary quartz.

The lowermost sill in Devils Gate is aphyric and in thin section resembles the chilled border phase of the main alaskite stock except that the grain size is slightly larger, and a little more muscovite is present. The remainder of the sills are porphyritic with numerous sodic oligoclase phenocrysts and random quartz (1 to 2 mm.) and muscovite phenocrysts (1 to 1.5 mm.) set in a microgranular aggregate of quartz, feldspar, and muscovite, the grain size averaging about .05 mm. in dimension. Owing to the small size of the crystals and clouding of the feldspar it is impossible to differentiate between the orthoclase and plagioclase in the groundmass.

RHYOLITE PORPHYRY

The rock from Mount Hope has a distinct porphyritic texture with quartz and sanidine phenocrysts ranging up to 5 mm, the quartz phenocrysts in slight excess of the sanidine. The groundmass consists entirely of microcrystalline quartz and feldspar, and judging from the chemical analysis (Table 2, no. 6) the groundmass feldspar is also sanidine. The feldspar is in part micropoikilitic and contains quartz. Most of the rock from the Mount Hope plug is sericitized, the feldspar phenocrysts and groundmass altered and some secondary quartz deposited in disconnected veinlets. A sample with a small amount of sericite was selected for analysis (Table 2, no. 6). It is remarkable in the exceedingly high potash and low soda content. This rock should properly be termed a potash rhyolite porphyry.

In the garnet-bearing rhyolite porphyry, the smoky quartz phenocrysts average about 3 mm, and many show pyramidal faces. The feldspar phenocrysts are slightly smaller and include calcic oligoclase and sanidine in approximately equal amounts. Under the microscope the feldspar phenocrysts seem to be clustered. Biotite is rare and in some specimens is of the greenish variety associated with chlorite; normally it shows intense pleochroism from pale yellow to very dark brown.

Reddish garnet crystals, ranging up to 2 mm, are scattered throughout the rock but represent less than 1 per cent of the specimen. In thin section some of the garnet is observed to be associated with quartz or feldspar phenocrysts, and some is isolated. The garnet is isotropic and distinctly pink in thin section. From its association and color, it probably belongs to the almandite-spessartite series, Pabst (1938) having described garnets of this series from lithophysae in rhyolites from Ely. The groundmass of the porphyry contains scattered oligoclase microlites separated by a micropoikilitic aggregate of quartz and untwinned feldspar, accompanied by some iron ores. The similarity in composition of the garnet-bearing porphyry to the alaskite (Table 2, nos. 4 and 5) is very striking. Possibly this indicates a close genetic relationship with different modes of formation. Also the contrast to the potash rhyolite porphyry of Mount Hope should be noted (Table 2, nos. 5, 6); the garnet-bearing porphyry contains appreciable soda and much more lime. The garnet-bearing porphyry appears to be a normal rhyolite porphyry.

The rhyolite flow near the mouth of Rutabaga Creek is similar to the above description of the garnet-bearing rhyolite porphyry except that the biotite has been largely replaced by granular magnetite, and the latter is more abundant in the groundmass. Garnet is absent.

QUARTZ LATITE

The average quartz latite is gray to pink with conspicuous white plagioclase phenocrysts 3 to 6 mm long. Associated phenocrysts are round glassy quartz up to 3 mm in diameter and dull black biotite up to 2 mm in diameter. In thin section, the plagioclase exhibits sharp albite twinning and faint zoning. Some glass inclusions may be present. Refractive indices indicate that the feldspar is largely andesine to calcic andesine, but in one rock the phenocrysts are sodic labradorite. The quartz is usually corroded and subordinate to the feldspar. In some samples of quartz latite, quartz is rare. Most of the biotite is replaced by granular magnetite, but a few shreds remain to indicate the original mineral. In a few thin sections, unaltered biotite is deeply pleochroic from pale yellow to deep brown. In some samples, small reddish-brown basaltic hornblende is present, rarely rimmed by magnetite. Accessory minerals are numerous apatite prisms and some zircon as well as magnetite. The groundmass ranges from isotropic to microcrystalline. Isotropic areas are local and never comprise an entire thin section; the average groundmass is cryptocrystalline with a "patchy" appearance suggestive of devitrification. In some thin sections the groundmass is composed of a mat of minute spherulites, .03 mm in diameter. Flow banding can be observed in some rocks. It is accentuated by red

iron oxide which is irregularly scattered throughout most of the quartz latites and accounts for their general pink color. In one specimen of pronounced flow banding, spherulites, 2 and 3 mm in diameter, are arranged parallel to the banding; these spherulites only feebly polarize

TABLE 2.—*Chemical analyses and norms*

	ANALYSES					
	1	2	3	4	5	6
SiO_2	55.56	57.66	69.35	74.15	74.97	76.15
Al_2O_3	15.15	13.59	15.22	14.96	14.12	12.75
Fe_2O_3	3.18	4.30	2.50	.17	.44	.00
FeO	6.34	6.26	.38	.64	.53	.09
MgO	4.33	2.79	.51	.15	.09	.07
CaO	8.15	5.86	2.40	.69	.83	.04
Na_2O	2.97	2.82	3.25	3.72	3.77	.50
K_2O	1.75	2.28	4.48	4.36	4.49	10.38
H_2O+	.59	1.10	.67	.70	.56	.09
H_2O-	.22	.93	.66	.06	.17	.00
CO_2	.....	.45	.....	.....	.....	.....
TiO_2	1.29	1.53	.40	.03	.02	.05
P_2O_5	.41	.51	.15	.10	.02	.03
MnO	.16	.15	.02	.07	.08	Tr
	100.10	100.23	99.99	99.80	100.09	100.15
	NORMS					
Q	8.58	15.22	27.21	33.62	33.61	31.38
Or	10.56	17.24	26.69	26.13	26.69	60.78
Ab	25.15	23.58	27.77	31.44	31.96	2.22
An	22.80	15.85	11.12	2.78	3.89	.....
C	.....	.....	.82	3.06	1.53	.....
Di	12.46	5.69	.....	.....	.....	.....
Hy	11.88	10.02	1.30	1.32	.73	.20
Il	2.43	2.89	.76	.....	.....	.15
Mt	4.64	6.26	.23	.23	.70	.....
Hm	.....	.....	2.40	.....	.....	.....
Ap	1.01	1.34	.34	.34	.....	.....
Cc	.....	2.20	.....	.....	.....	.....

1. Andesite from large mesa 4½ miles northwest of Mount Hope.
2. Andesite dike from 9000 feet elevation, west slope of Roberts Creek Mountain.
3. Quartz latite from summit of hill in southeast corner of quartz latite area.
4. Alaskite from near top of Whistler Mountain.
5. Rhyolite porphyry from plug north of Mount Hope.
6. Potash rhyolite porphyry from Mount Hope.

All analyses by G. Kahan.

light. In some sections, the quartz latite may be partly granulated, no doubt owing to protrusion in a highly viscous to solid state.

The dark-gray perlitic quartz latite contains the same phenocrysts, including the basaltic hornblende, as the average pink quartz latite but in addition has hypersthene, with pronounced pleochroism. The perlitic groundmass is charged with numerous microlites and crystallites separated by clear glass with a refractive index of $1.501 \pm .003$.

A microscopical examination indicates a normal dacite, but the chemical analysis (Table 2, no. 3) shows that the potash content (4.48 per cent) is far too high for such classification, and it is more appropriately called a quartz latite. As with many latites, the potash must be present largely in the groundmass, with the exception of a small amount in the biotite.

ANDESITE

The older andesite flows that antedate the quartz latite are composed almost exclusively of labradorite, augite, and magnetite. The texture is aphyric; visible phenocrysts are rare and consist almost entirely of plagioclase, usually calcic labradorite, 1 to 2 mm long. Except for the surface vesicular phases, the andesite has an intergranular to intersertal texture, and the labradorite crystals range from An_{50} to An_{60} and are three times as long as the greenish-gray augite granules. The labradorite grain size varies from .1 mm long in one extreme to an average of .3 mm in another. In one slide, an augite microphenocryst has a hypersthene core; normally this latter mineral is absent. A small amount of olivine was noted in one sample. The magnetite may appear as distinct crystals or as dust in the glass if the texture is intersertal. If all the magnetite is in large crystals, the rock is light gray. Apatite is a common accessory. Cristobalite is present in practically all samples of the andesite, either as spheroidal .2 to .3 mm in diameter lining vesicles or more commonly coating irregular-shaped cavities into which the feldspar projects. The labradorite in these cases may have a very narrow outer rim of albite which is in optical continuity with the labradorite. If the texture is intersertal, the interstitial glass varies from black opaque dusted with magnetite to pale gray shot through with long slender needles too minute to polarize light. In one slide, some of the interstitial glass is reddish, with some birefringent fibers suggestive of chlorophaeite and its alteration products (Peacock and Fuller, 1928, p. 369). The surface vesicular phase is always black in hand specimens and thin section, and the labradorite and augite are completely separated by a black opaque mesostasis, forming a hyalo-ophitic texture.

The classification of the older andesite presents a problem familiar to all petrographers, for it is not a typical andesite in that the modal feldspar is labradorite. On the other hand it is not a typical basalt in that the silica content is high (Table 2, no. 1), raised possibly 1 per cent by the cristobalite. However, the normative plagioclase is andesine, and the normative salic minerals total 67 per cent. Obviously this rock is on the border line between andesite and basalt, and some petrographers will prefer one term and some the other. Without any strong convictions, the rock is here called an andesite.

The dikes are similar to the flows, except that the dikes have no cavities and no cristobalite. Hypersthene is present in small amount in most of the thin sections, and the magnetite always appears as definite crystals. The texture is intersertal to diabasic, and the grain size varies greatly from dike to dike. In the coarsest texture observed, the feldspar crystals average .5 mm long and, in the finest, .15 mm. Where the texture is intersertal, the interstitial material may be light-colored glass riddled with slender prisms of apatite or consist of a grayish cryptocrystalline aggregate. In some dikes the interstitial material may be orange, opaque, with an index below balsam, and containing some birefringent fibers that suggest chlorophaeite and its alteration products. In several dikes, the light-colored base interstitial to the augite and labradorite weakly polarizes light and is arranged in radiating bundles. The index of refraction is below balsam, indicating that this material may be an alkali feldspar. Quartz was observed in small irregular grains in this aggregate which suggests that the final liquid crystallized to quartz and alkalic feldspar. Apatite is common in all these interstitial areas. A holocrystalline diabasic texture is not common and usually embraces only a part of a thin section. Grains and aggregates of calcite are common in all the dikes studied, and, in a few, rounded quartz grains associated with calcite indicate that some of the quartz may be xenolithic. No reaction rims were noted around either the calcite or larger quartz crystals. The freshness of the associated pyroxene and feldspar indicates that the calcite represents xenocrysts from the wall rock.

Even if the dikes represent feeders for the early andesite flows, the composition is different (Table 2, nos. 1, 2), for the analyzed dike rock is higher in silica and potash and lower in magnesia and lime, placing it definitely among the andesites.

The andesite resting on the quartz latite in the northeast corner of the Roberts Mountains is dark gray with scattered andesine and numerous small augite phenocrysts. Thin sections rarely include the plagioclase phenocrysts, but the pale-gray augite phenocrysts are numerous. The groundmass is pilotaxitic, with andesine and augite microlites dusted with magnetite.

The hornblende andesite from the west side of the Roberts Mountains is conspicuously porphyritic with large phenocrysts of andesine-labradorite and basaltic hornblende, the latter rimmed with granular magnetite. The groundmass is pilotaxitic stained with red iron oxide. Stubby faintly pleochroic yellow prisms of apatite are accessory.

OLIVINE BASALT

Olivine basalt appears in only one area, north of Garden Pass, and in the massive interior of the flow this lava is holocrystalline with an ophitic to subophitic texture. About 5 per cent consists of olivine crystals, partly altered to iddingsite, and associated with labradorite tablets .3 mm long separated from or enclosed by purplish-gray, nonpleochroic augite. Distinct crystals of magnetite and slender prisms of apatite are important accessories.

CHEMICAL CHARACTERS OF IGNEOUS ROCKS

The number of chemical analyses available from the Roberts Mountains is insufficient to permit construction of a variation diagram that has real meaning. Even when the analyses of the igneous rocks from the neighboring Eureka district are added, there is a scattering of points that allows considerable latitude in drawing the connecting curves. On the variation diagram prepared in studying the analyses, the potash curve had higher value than the soda curve where silica exceeds 60 per cent. Nolan (1935, p. 50) commented on the fact that the volcanic rocks in Utah and New Mexico have appreciable quantities of potash. In order to compare the central Nevada volcanic rocks with those of other parts of Nevada, Utah, and California the k ratio—that is, the molecular ratio of potash to total alkalies—has been determined from all available analyses from these areas. Since many of the available analyses record only the silica, soda, and potash content, no other ratios could be computed, and the k ratios have been plotted against the silica content (Fig. 3). It should be emphasized that, if the weight per cent of soda and potash are equal, the k ratio will equal 0.4, and any higher k value indicates that the weight per cent of the potash exceeds the weight per cent of soda. Figure 3 shows that most of the Utah lavas have a k ratio equal to or exceeding 0.4, and those below this value are not appreciably smaller. A few Utah lavas have a rather high k value. However, the volcanic rocks from California chosen from the Sierra Nevada and Cascade Range have a much lower k ratio than the Utah lavas except for the latite from Tuolumne Table Mountain, which is indicated separately in Figure 3. Also the silicic rocks from both areas have comparable k values. However, the intermediate and basic lavas differ considerably. The rocks from Roberts Mountains and the Eureka district, with but one exception, have k values close to or exceeding 0.4.

Some of the lavas from western Nevada have low k ratios, and others have higher values. One difficulty is that some of these lavas have been collected from mining districts such as Tonopah, Goldfield, and Virginia City, where there is always the possibility that some selective leaching

of one or the other alkalies may have occurred during the process of hydrothermal alteration that accompanied metal mineralization. Terzaghi has suggested (1935, p. 378) that many potash-rich rocks are the result of alteration, and Fenner (1934; 1936) has described excellent

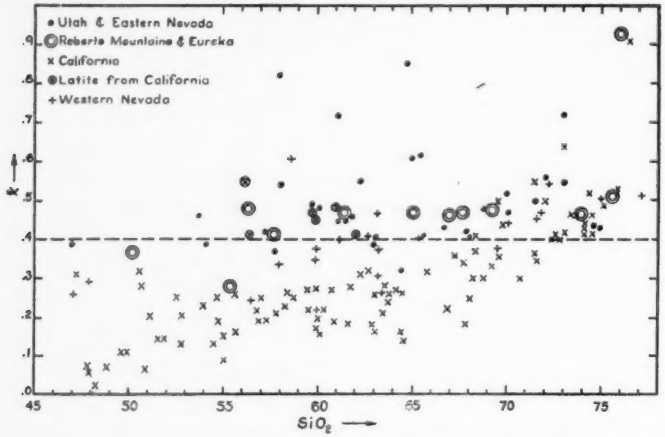

FIGURE 3.—*Diagram of the k ratio plotted against SiO_2 content*

examples of potash enrichment in the hydrothermally altered lavas of Yellowstone.

The rhyolite porphyry from Mount Hope is high in potash, and some hydrothermal alteration has taken place in the plug, although the analyzed sample was carefully selected to avoid alteration. However, as Fenner states (1934, p. 242), fresh lavas with high content of silica and potash which have not undergone hydrothermal metamorphism resulting in potash enrichment should only contain phenocrysts of quartz and orthoclase, like the Mount Hope porphyry. In the samples studied by Fenner, the potash enrichment was confined to the groundmass, and the plagioclase and pyroxene phenocrysts "remain as witnesses of the original composition, . . . incompatible with the present groundmass". So if hydrothermal alteration is responsible for the potash enrichment of the Mount Hope porphyry it differs from the Yellowstone examples in that the feldspar phenocrysts are now sanidine, and under the microscope there is no suggestion that they represent replaced plagioclase. In the other rhyolite porphyries, sanidine and plagioclase appear together. Since no definite evidence supports the suggestion that the potash enrichment followed hydrothermal alteration, it can only be considered a

possibility. This same conclusion can be applied to all the rocks from the Roberts Mountains and equally well to those from Utah. Apparently the potash enrichment is regional and cannot be explained simply by hydrothermal alteration. It is not in the province of this paper to advance an explanation of the potash enrichment, but the enlargement of the Utah and New Mexico potash province to include central Nevada should be emphasized.

SUMMARY OF CONCLUSIONS

In central Nevada rocks which represent western graptolitic facies of Lower and Middle Ordovician age have been thrust eastward at a low angle over a section of sediments ranging from Cambrian to Permian. Horizontal displacement of at least 16 miles is indicated, with possibility of much greater movement. It is concluded that folding of the Paleozoic strata below the thrust preceded the major thrusting. Thrust sheet and partial cover of younger volcanic rocks have been broken by normal faults. No precise dating is assigned to the periods of folding, thrusting, or later normal faulting. The post-thrusting igneous rocks have a high potash content, unlike those in California, but are similar to the lavas of Utah and New Mexico.

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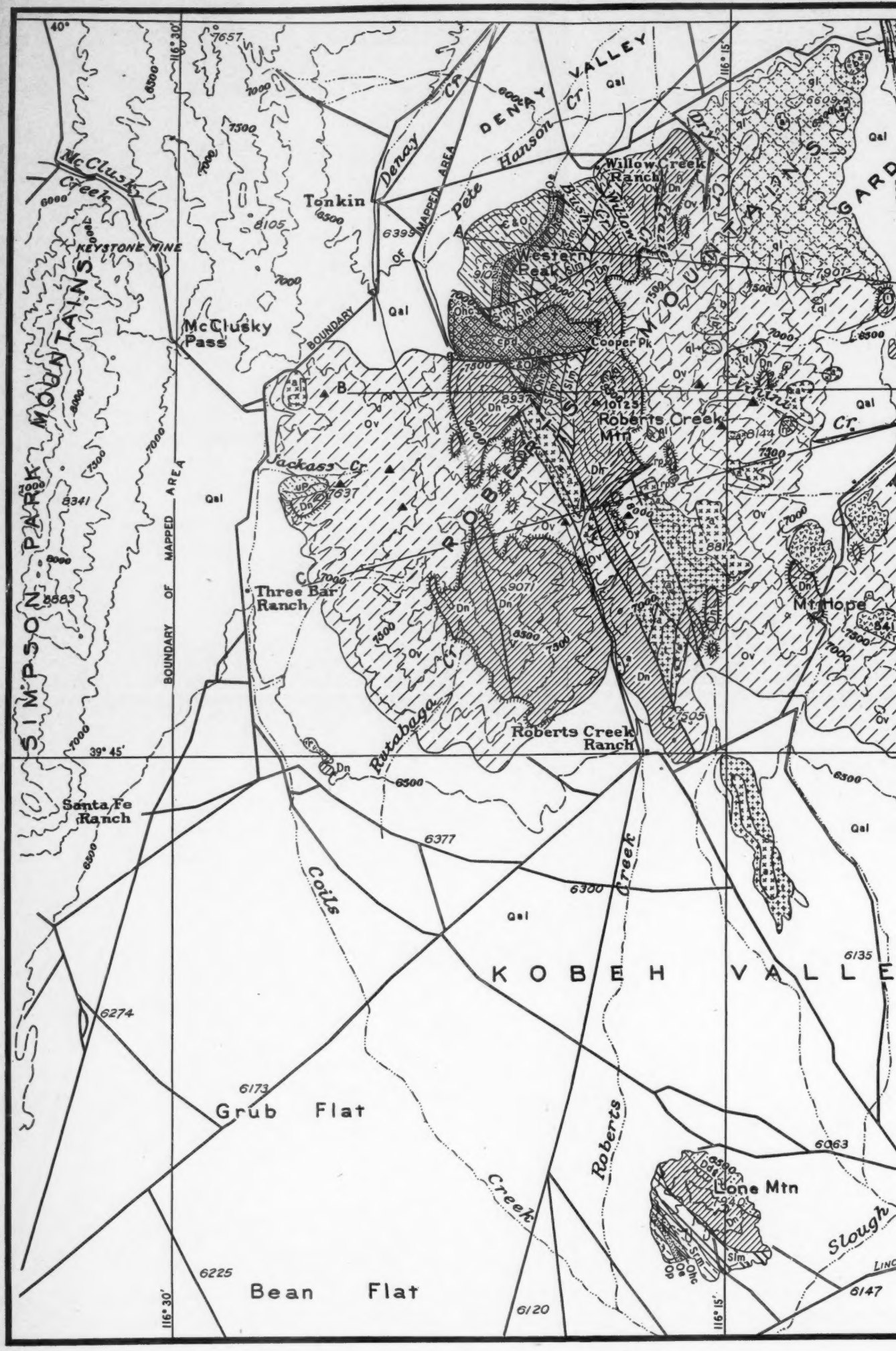
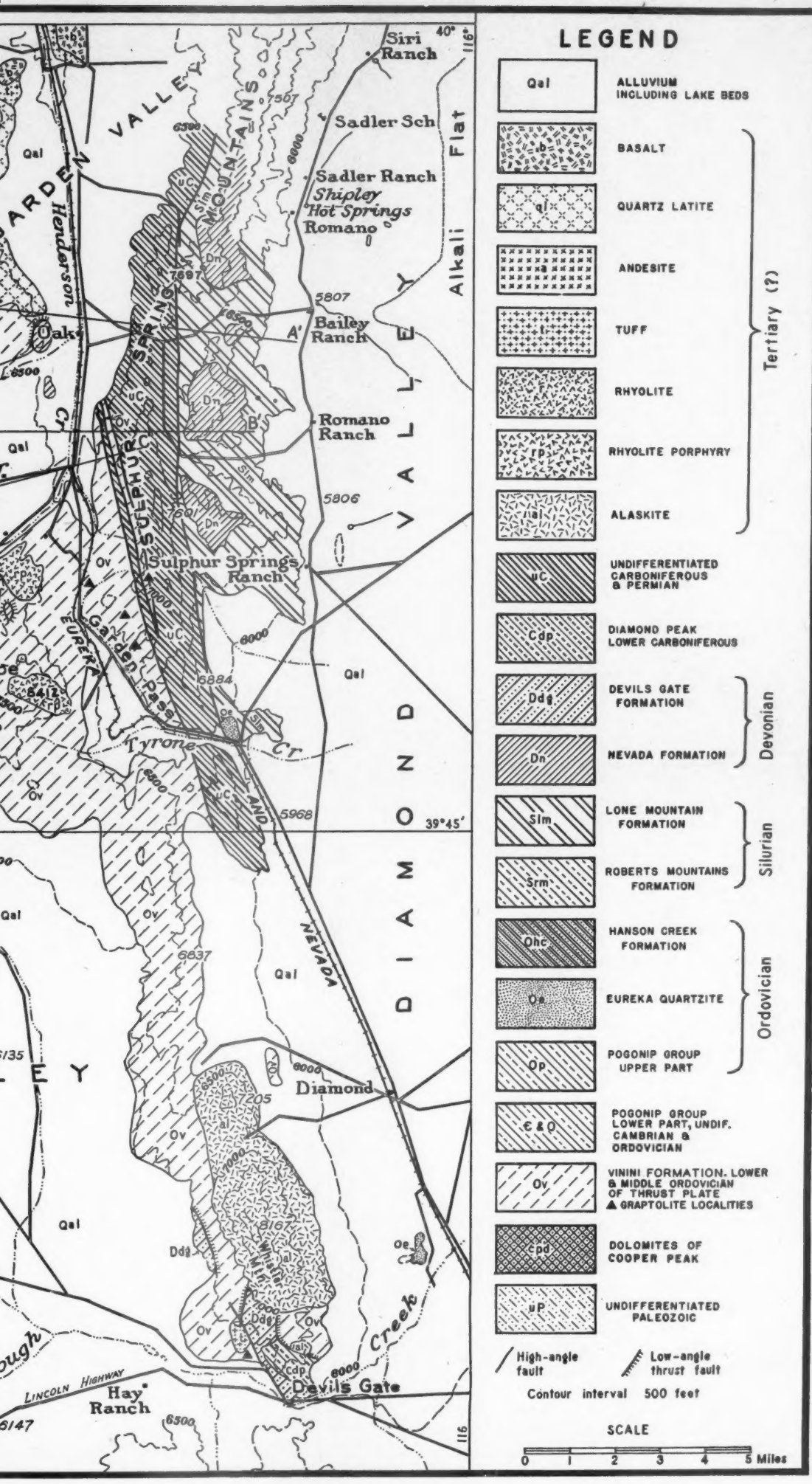


RECONNAISSANCE GEOLOGIC MAP OF ROBERTS MOUNT



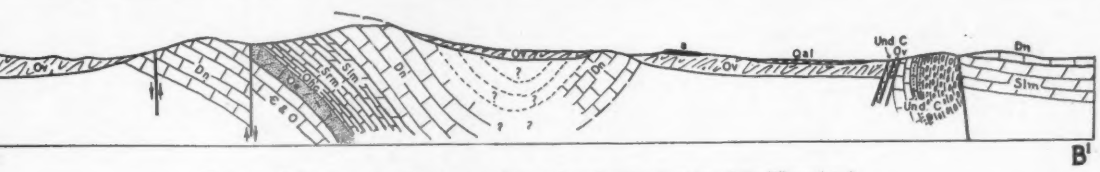
LEGEND

Qal	ALLUVIUM INCLUDING LAKE BEDS	
b	BASALT	Tertiary (?)
ql	QUARTZ LATITE	
a	ANDESITE	
t	TUFF	
r	RHYOLITE	
rp	RHYOLITE PORPHYRY	
rial	ALASKITE	
uC	UNDIFFERENTIATED CARBONIFEROUS & PERMIAN	
Cdp	DIAMOND PEAK LOWER CARBONIFEROUS	
Ddg	DEVILS GATE FORMATION	Devonian
Dn	NEVADA FORMATION	
Slm	LONE MOUNTAIN FORMATION	Silurian
Srm	ROBERTS MOUNTAINS FORMATION	
Ohc	HANSON CREEK FORMATION	Ordovician
Oe	EUREKA QUARTZITE	
Op	POGONIP GROUP UPPER PART	
€ & O	POGONIP GROUP LOWER PART, UNDIF. CAMBRIAN & ORDOVICIAN	
Ov	VININI FORMATION. LOWER & MIDDLE ORDOVICIAN OF THRUST PLATE ▲ GRAPTOLITE LOCALITIES	
cpd	DOLOMITES OF COOPER PEAK	
uP	UNDIFFERENTIATED PALEOZOIC	

High-angle fault — Low-angle thrust fault

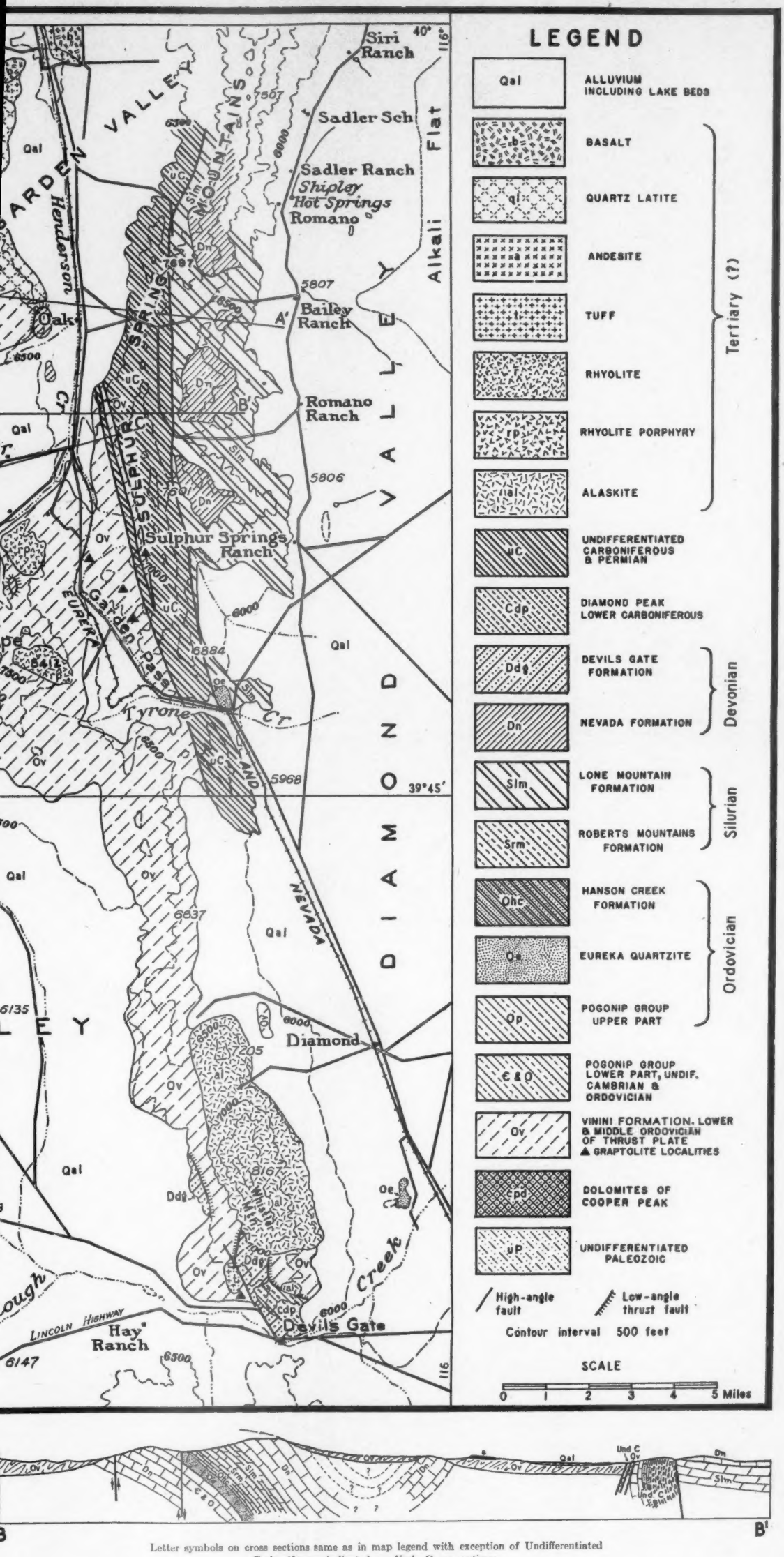
Contour interval 500 feet

SCALE 0 1 2 3 4 5 Miles



Letter symbols on cross sections same as in map legend with exception of Undifferentiated Carboniferous indicated as Und. C on sections.

RECONNAISSANCE GEOLOGIC MAP OF ROBERTS MOUNT



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MOUNTAINS WITH CROSS SECTIONS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 53, PP. 1729-1794, 1 PL., 1 FIG. DECEMBER 1, 1942

CORRELATION OF THE DEVONIAN SEDIMENTARY FORMATIONS OF NORTH AMERICA

BY G. ARTHUR COOPER *(Chairman)*, CHARLES BUTTS, KENNETH E. CASTER, G. H. CHADWICK, WINIFRED GOLDRING, E. M. KINDLE, EDWIN KIRK, C. W. MERRIAM, F. M. SWARTZ, P. S. WARREN, A. S. WARTHIN, AND BRADFORD WILLARD

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INTRODUCTION

HISTORICAL BACKGROUND

The Devonian system became established in North America in 1847 through the writings of Verneuil, whose views were made known largely by Hall's translation. In 1851 Hall accepted the Devonian system and the European arrangement of it. Since then the system has been elaborated and expanded by the addition of the Helderberg stage. In this century a few correlation charts have been prepared (Ulrich, 1911; Schuchert, 1910; Shimer, 1934), but none considered Devonian rocks in

detail. The present chart is therefore the first comprehensive one to be offered.

ACKNOWLEDGMENTS

This chart has been compiled by the writer with the help of several colleagues and the close guidance of Dr. Edwin Kirk. Cooper is mainly responsible for the arrangement of the Middle Devonian and the Devonian of parts of western United States and of Gaspe, Quebec. Swartz arranged the Lower Devonian columns of the Appalachians, Butts advised on the sections in the Southern Appalachians; Willard furnished the columns above the Onondaga for Pennsylvania; Caster examined and approved the columns for northwestern Pennsylvania and southwestern New York; Merriam aided in the preparation of the sections for the Eureka district, Nevada and California; Kindle furnished the columns for the Northwest Territories, Canada; Warren submitted sections and correlations for the Canadian Rockies; Warthin contributed notes on the Skunnemunk outlier; Mr. Wilson M. Laird kindly furnished new information on southwestern Pennsylvania; Dr. M. A. Stainbrook helped with a discussion of the Independence shale; Dr. G. M. Ehlers gave information on the black shale sequence of Michigan; Dr. W. L. Bryant helped with a discussion of the age of the Escuminac formation of Quebec. Dr. Winifred Goldring furnished a discussion of the Schoharie formation in New York. New information on the Devonian of Michigan and the Midwest is furnished by Cooper and Warthin. In the discussion accompanying the chart each contribution not furnished by Cooper bears the name of the contributor.

GEOGRAPHIC ARRANGEMENT

To show the facies of the sediments best the columns start with Alabama and Georgia and proceed northeastward along the Appalachians into the Catskill "delta" region southwest of Albany, New York, and then swing sharply westward to Lake Erie, southwest to northern Ohio, and south along the east flank of the Cincinnati Arch to southern Kentucky. From Ohio the sequence is extended to Michigan and the Midwest. This arrangement shows well the great extent of the red-bed facies and the passage westward of the normal marine sequence to black shales in the Midwest.

The Midwest columns are made to adjoin those of Manitoba where the *Stringocephalus* zone is well developed. With this zone as the main tie the sections of the Great Basin, Canadian Rockies, and Northwest Territories are placed next to the Manitoba sequence. The columns for New England, Maritime Canada, and Gaspe Peninsula show a great development of the Lower Devonian and do not fit well at either end of the chart.

These might have been better placed adjacent to the New York columns, but this would have obscured the facies relations of the geosyncline.

DIFFICULTIES IN CORRELATION

Many of the correlations indicated are only tentative; the reader is warned not to accept the chart as a final or fixed expression of correlation; *it is a statement of existing knowledge only*. The major factors preventing accurate correlation at the present time are: (1) lack of detailed field work in certain areas, and (2) inadequate paleontology.

(1) Many Devonian areas of the United States and Canada, such as the Great Basin and other western areas, are known only superficially. Merriam's recent work has promoted better understanding of the Devonian of the West, but much still remains to be done. More comprehensive studies are needed on the Jefferson limestone of Montana and Wyoming, the Devonian of California, of New Mexico, and of southern Nevada. Stoyanow has made a significant contribution to the knowledge of the Devonian of Arizona.

Most of the Devonian areas in the Midwest are so well known that the problem there is for the paleontologist rather than for the stratigrapher and areal geologist. In the East a great blank exists in the knowledge of the Devonian of the Appalachians south of Maryland. The generalities of the outcrop belts are known, thanks to the mapping of Butts, but details of the stratigraphy such as facies relationships have never been worked out.

(2) If detailed correlations in this country are ever to be perfected many more fossils must be described. For years we have talked of Traverse faunas, Cedar Valley faunas, and others, but most of their species are yet unnamed. The writer has about 250 species of brachiopods alone from the Traverse group of Michigan, and most are new. Throughout the Appalachians and New York many important species are still undescribed. Settling of the Devonian-Mississippian boundary in the Appalachians and Allegheny Plateau awaits Caster's promised description of the Conewango and related faunas. The major outlines of the Devonian stratigraphy of Pennsylvania have been laid down by Swartz, Cleaves, and Willard, but the paleontology and unraveling of important faunal zones are still to be done. Only through such detailed work will exact correlation of formations of New York and Pennsylvania be possible. In the Midwest, redescription of the Cedar Valley (now being undertaken by M. A. Stainbrook), Callaway, Independence, Grand Tower, and St. Laurent faunas is urgent.

Including Walcott's paleontology of the Eureka district, Nevada, and the Territorial Survey reports, only a handful of fossils has been described

from the West, and many are now known by eastern names. Most of the descriptions of species need revision.

STANDARD SECTION

The standard column of the Devonian of the United States is in New York where an almost unbroken and undisturbed sequence extends from the Coeymans limestone of the Helderberg stage into the Mississippian system. The only significant gap is that of the *Stringocephalus* zone which apparently pinches out to the southeast from Presque Isle County, Michigan. Nevertheless, the position of this zone is now known, and the upper Hamilton and Tully (Taghanic) are thought to represent its upper part. With this qualification the New York column is an excellent standard, and all the sequences of the Midwest and West have been compared to it.

DIVISIONS OF THE DEVONIAN

Ever since its establishment on this continent the Devonian system has been separated into a lower, middle, and upper part. This threefold arrangement unfortunately has become intrenched in the literature. As classified, the divisions are unequal, the Upper Devonian in general outweighing the other two, and the Lower Devonian being represented by the Helderberg and Deerpark stages only. The writer has long wondered whether these divisions of the American Devonian actually correspond with those of the European column. It seems wise therefore to divide the American Devonian into stages and reserve judgment on the parts to be placed in the lower, middle, and upper divisions.

According to present American classification the Helderberg and Oriskany constitute the Lower Devonian; the Onondaga and Hamilton form the Middle; and the remainder is included in the Upper Devonian. By comparison with the European column a somewhat different arrangement would include the Onondaga besides the Helderberg and Oriskany in the Lower Devonian. In Germany *Paraspirifer cultrijugatus* characterizes the Upper Coblenzian and Eifelian. The former, at the top of the Lower Devonian, seems to be the equivalent of the Onondaga, while the Marcellus correlates with the Eifelian rather than the Givetian where it has hitherto been placed. This is based on the range of *Paraspirifer* from the Onondaga through the Marcellus and the fact that the Marcellus assumes an Eifelian or "reef" facies in the Midwest and Canada. It is thus contended that the Onondaga with its "reefy" facies has been correlated incorrectly with the "reefy" Eifelian and that the shaly Marcellus actually correlates with the Eifelian. This is borne out by the fact that in Michigan the *Stringocephalus* zone rests not on the Onondaga but on the Dundee or calcareous equivalent of the Marcellus.

Essentially the same condition holds in Lone Mountain, Nevada, where a fauna suggestive of the Delaware limestone (*Martinia* zone of Merriam) underlies the *Stringocephalus* beds and overlies an Onondaga equivalent. If the Marcellus is Eifelian the Onondaga becomes Lower Devonian.

A major change is also necessary in the Middle Devonian: the transfer of the Tully to its old position at the top of the Middle Devonian. The Tully contains a Middle Devonian fauna and is actually the equivalent of the upper Givetian, not earliest Frasnian as hitherto claimed.

In subdividing the Devonian the writer is employing several new stage names. These stages represent groupings of formations chiefly on a faunal and paleogeographic basis. Seven of the names are new, but two are familiar group terms elevated to the rank of stage.

Helderberg stage.—The group term of this name is elevated to stage rank. The type section is in the Helderberg Mountains of New York.

Deerpark stage.—This stage includes the Oriskany and its correlates. The type section is in southeastern Deerpark Township on the west slope of the Shawangunk Mountains facing Port Jervis, Sullivan County, New York.

Onesquethaw stage.—This stage includes the sediments of the Esopus, Schoharie, and Onondaga and their correlates elsewhere on the continent. The type section is in the Helderberg Mountains west of Clarksville and facing the valley of Onesquethaw Creek in Albany County, New York.

Cazenovia stage.—This is a revival of the Cazenovia group of Conrad (1841) and Vanuxem (1842) as a stage term. The name as here used includes the strata from the top of the Onondaga to the base of the Centerfield, or the Marcellus and Skaneateles formations. The type section is in the township of Cazenovia, New York, where the entire sequence occurs.

Tioughnioga stage.—This includes the Ludlowville and Moscow formations which are closely related faunally and are mainly restricted to the eastern part of the Devonian geosyncline. Except for the Centerfield and its equivalents this stage is not represented in the Ohio and Mississippi valleys. The name is taken from the headwaters of Tioughnioga River in the south half of the Cazenovia quadrangle, New York. The interval embraced by the new name is from the base of the Centerfield to the base of the Tully limestone.

Taghanic (or Taughannock) stage.—This includes the sediments of the Tully and Geneseo with their correlates elsewhere on the continent. The type section is in Taghanic (Taughannock) Falls Park northwest of Ithaca, west side of Cayuga Lake, New York.

Finger Lakes stage.—This new name includes the strata from the top of the Geneseo shale to the base of the Chemung stage (Cayuta shale and sandstone and Grimes sandstone). The type section is in the Finger Lakes country of New York where these rocks are well exposed on all the larger lakes. The sequence thus includes the Genesee and Naples groups as conceived by Chadwick which are closely linked faunally.

Chemung stage.—The group term Chemung is here elevated to stage rank because of the widespread and distinctive character of the fauna. The stage has the same limits that Chadwick gave to the group.

Cassadaga stage.—This is a new name for the Canadaway and Conneaut groups which are faunally related to the Chemung and to each other. The name embraces the sequence from the Dunkirk shale to the Wolf Creek-Panama conglomerate. The type section is the headwaters and valley of Cassadaga Creek in the Dunkirk, Chautauqua, and Jamestown quadrangles, New York.

Conewango stage.—Above the Cassadaga stage (top of Conneaut) the fauna is distinctly different from that below, and the Conewango group term is therefore here elevated to that of a stage.

FACIES

GENERAL STATEMENT

The Devonian of New York State presents an excellent example of shifting facies, particularly in the post-Onondaga parts where the changes of sediment have been traced from red beds in eastern New York to black shales and limestone in Ohio. In general the change is from red sands and conglomerates to gray, fine-grained sandstones to dark siltstones, then to dark-gray and black shales, and finally to calcareous shales and limestones containing coral plantations and bioherms. The pattern of these shifts is now so well known that relationships not yet recognized in parts of the Appalachian geosyncline can be anticipated.

Following the Onondaga the great clastic flood was initiated by the Marcellus. In eastern New York the lowest Marcellus is a fine sandy gray shale which gradually passes into black shale and black limestone near Cayuga Lake. While the sands of the Mount Marion formation were being deposited in eastern New York, black muds of the Chittenango were forming in east-central New York. In late Marcellus time the first nonmarine beds, the Ashokan sandstone, appeared in eastern New York and were followed by red beds of the Skaneateles. The black shales continued to form throughout the rest of Hamilton time but appeared farther and farther westward and also higher and higher in the section so that black and gray mud facies occur in all the Hamilton stages. Obliquely

above the black muds occur the silts and fine sands of the next facies. These siltstones are overlain obliquely by coarser sands that occupy the eastern part of the State and extend as far west as central New York. The red bed or nonmarine facies obliquely overlies the sandy facies and in the Hamilton extends westward only as far as Schoharie Valley.

A slight break in sedimentation occurs at the top of the Hamilton resulting from formation of a shoal on the site of Lake Erie probably in connection with movements of the Cincinnati arch. At any rate the movement is shown in a slight break traceable nearly to Schoharie Valley where all evidence of disconformity is lost. Following this break the Tully sediments show nearly the same facies shifts as the Hamilton. The calcareous facies is located between Canandaigua Lake and Chenango Valley. In Unadilla Valley, 10 miles east of Chenango Valley, the Tully is represented by clastics which in Butternut and Otego valleys are more than five times as thick as the limestones. In Schoharie Valley red beds of Tully age appear in the sequence, and conglomerates and red beds at the top of the Catskill Mountains facing the Hudson Valley are thought to represent this formation.

In post-Tully time the same sequence of facies occurred with the red beds pushing progressively westward until they reached the meridian of Canandaigua Lake. The black shale occupies most of the section between the Genundewa and the Gowanda. Fine-grained gray sands and siltstones lie between the reds and blacks.

West of New York, facies shifts are still to be recognized. The Helderberg stage and most of the Deerpark are overlapped by the Onondaga limestone, but in the Hamilton the black shales of New York interfinger with bluish Arkona clay shales and the Delaware limestone. In Alpena and Presque Isle counties, Michigan, the Marcellus of New York is represented by buff Delaware-Dundee limestones with "reefs" of the same age located in southwestern Ontario and the James Bay region. The Skaneateles dark muds of the Lake Erie shore are represented in Michigan by thick limestones containing layers of calcareous shale (Bell to Alpena) and including large bioherms and biostromes of corals and stromatopores. Thus the limestones of Michigan represent the "reef" or shelf facies of the lower Hamilton. Southwest of New York the Logansport and Beechwood limestones of Indiana also represent the same shelf facies.

The Upper Devonian of New York contains no calcareous facies, and this phase of sedimentation is not encountered east of the Mississippi. West of the Mississippi calcareous shale facies and some Upper Devonian limestone occur in Iowa and Missouri, but the great development of calcareous Upper Devonian is in the Great Basin. It is therefore difficult

to correlate the sands and shales of the Upper Devonian of New York with the limestones of the West.

These facies changes are also well developed in Pennsylvania where they have been described by Chadwick, Willard, Caster, and Laird. The same facies should also be well represented in the Appalachians southwest of Pennsylvania but have never been worked in detail. The outcrop of the Devonian cuts east across New York into the red beds southwest of Albany. It then turns southwestward and runs along the Catskill Front. Between Albany and Napanoch, New York, the two upper stages of the Hamilton are represented by nonmarine beds, but, to the southwest, marine beds dominate the section which is wholly marine from Port Jervis southwestward into Pennsylvania, Maryland, Virginia, and West Virginia. Red beds occur in the lower part of the Upper Devonian of the Delaware River sequence northwest of Port Jervis but, continuing southwest or toward the seaward part of the geosyncline, marine beds are more frequent and finally occupy the entire sequence. The Finger Lakes stage is mainly marine across Pennsylvania, Maryland, Virginia, and West Virginia. The reds of the higher Upper Devonian give way to marine sediments in western Pennsylvania, and representatives of the Canadaway and Conneaut groups are known in western Virginia. It is thus clear in the Appalachians that, as the folded belts bring up sediments representing more seaward parts of the geosyncline, the sequence becomes more and more like that of the New York outcrop. In other words the Appalachian sequence when once unfolded should in its major features and its faunal aspect duplicate the New York succession.

BLACK SHALE

Much discussion has centered around the age of the black shales of the Midwest and South; one school of thought claims that these shales are Devonian, while the other believes they are Mississippian. Because of the established facies relationships of the Devonian of New York and Pennsylvania, the writer believes that much of the black shale of Ohio, Indiana, Kentucky, Illinois, and Michigan is Devonian. It is still a problem where to assign some of the black shale of the South.

Portions of the black shale containing *Lingulipora, Schizobolus, Stylio-lina, Hypothyridina,* and *Leiorhynchus quadricostatus* are generally conceded to be of Devonian age. Such deposits occur in Virginia, Indiana, Kentucky, Tennessee, Oklahoma, Arkansas, and possibly Alabama. In New York, *Schizobolus* occurs in the upper beds of the Hamilton and becomes extinct in the Naples group. Besides occurring in the Hamilton and Geneseo, it is reported from the Marcellus in Virginia. This particular black shale (Millboro) in Virginia may conceivably represent not

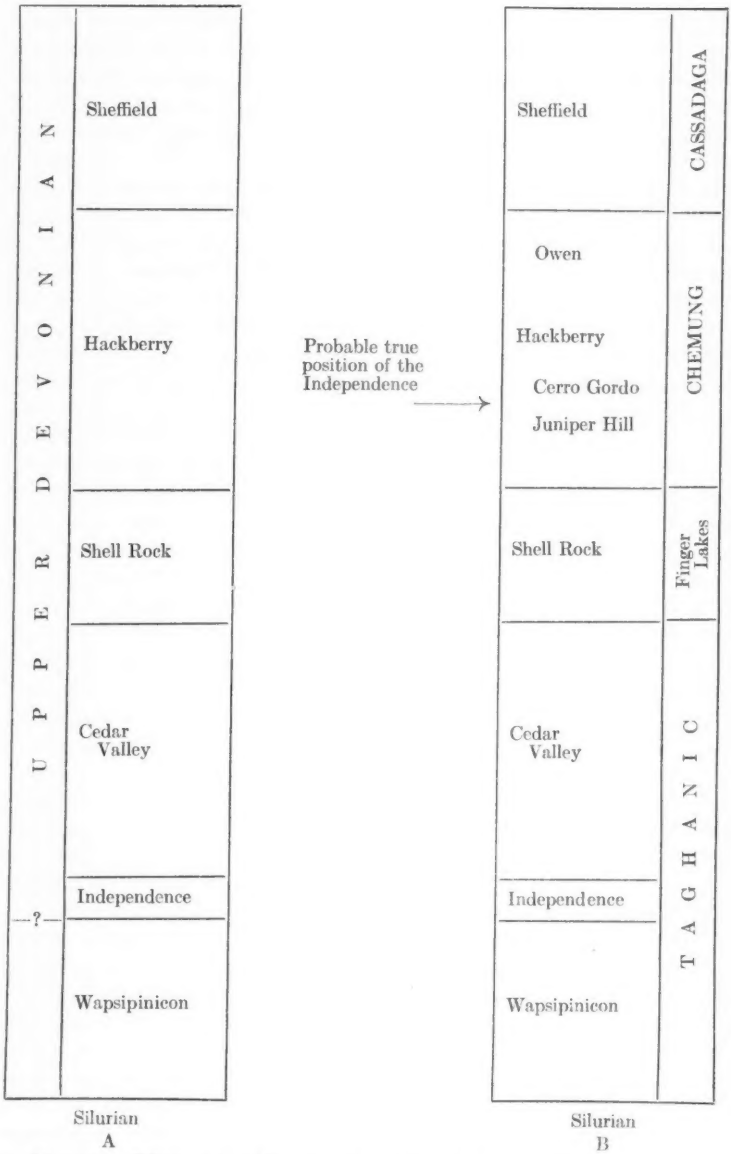


FIGURE 1.—*Diagram showing contrasting views of the interpretation of the Independence shale*

A. Stainbrook; B. Cooper and Warthin.

only the Marcellus but the entire Hamilton. In the Midwest and in Tennessee, *Schizobolus* has generally been assigned to the Geneseo, but the presence of *Hypothyridina* in similar shales suggests that perhaps they should be assigned to the Tully. As both the Tully and Geneseo are here placed in the Taghanic stage this question does not greatly affect accurate correlation.

The real problem of the black shale is not with the beds carrying *Schizobolus,* but with the overlying strata. In general this portion has few fossils, and, except for the Kinderhookian (Hamburg) fauna at the top, has yielded no diagnostic specimens. The brachiopod *Barroisella subspatulata* has often been regarded as a Mississippian guide fossil, but in the New Albany shale it occurs in or near a green band not far above the Geneseo equivalent which constitutes the lower 10 feet of shale. In Michigan the writer collected this species in a patch of green shale on the floor of the shale pit at Paxton, 8 miles west of Alpena, below concretions containing the Devonian goniatite *Tornoceras.* As this goniatite is unknown in the Mississippian, the Devonian age of *Barroisella subspatulata* is fixed. This common brachiopod has been reported also from the Mountain Glen shale of Illinois.

When the facies relationships of the Upper Devonian are considered it would be expected that the great mass of sediments of the Appalachian geosyncline would be represented by black shales in the off-shore and pre-shelf region. Study of the Hamilton and Upper Devonian corroborates this. In northern Ohio the Chagrin shale represents the silty facies of the Conewango group and part of the Conneaut, and, west of the Chagrin area, black shale appears until finally the Huron shale is thought to represent the black shale facies of the Chagrin. The Ohio shale is believed to equal the Huron and "Portage" black shale.

Passage of the Upper Devonian sediments to black shale is accompanied by thinning of the sequence. For example, the Oatka Creek shale of the Marcellus stage is 50 feet thick in Erie County, New York, while its coarser equivalent in the Catskill region is about 1300 feet thick. The Upper Devonian black shales thin to the west, except locally, but it cannot yet be proved whether the outlying strata equal all the Upper Devonian or whether there is overlap. In the latter case the beds farthest out would be youngest. Local thinning by unconformity at the top is known, but it has not been demonstrated as universal over the range of the black shale.

In southwestern Virginia the gray Brallier shale represents part of the Naples group and possibly some of the Chemung as restricted, but black fingers have been detected in this formation which Butts (oral communication) thinks may represent the incoming of the "Chattanooga"

facies. This is possible, but the southern or type Chattanooga has not been dated so low in the Upper Devonian.

Although direct fossil evidence of the age of the black shales has not yet been found the presence in a number of areas of a basal Kinderhook fauna gives a definite upper limit to the Devonian shale. The fauna in question is that of the Hamburg oölite that occurs in the Glen Park limestone in Calhoun County, Illinois, and can be identified at a number of localities east and west of Calhoun County. To the west the Glen Park limestone contains this fauna. To the east it has been seen at the top of the New Albany shale (Huddle, 1933) and it occurs also in the Bedford shale of Ohio. Foerste (1909) traced the Bedford fauna into eastern Kentucky. Savage and Sutton (1931) report it in south-central Kentucky, and J. H. Swartz (1924) describes it at Eulie, Sumner County, central Tennessee. The fauna reported by J. H. Swartz (1929) from the Olinger shale of eastern Tennessee may be a far-removed outpost of the same assemblage.

The Devonian or Mississippian age of the Hamburg fauna has not yet been settled. Although originally described as Mississippian (Weller, 1906) a Devonian age was claimed by Girty (1912) for its equivalent in the Bedford shale. More recently Branson and Mehl (1938) and Branson (1938) champion the Devonian claim. The majority of species do have unmistakable Devonian affinities and include some familiar types: *Nucleospira* and *Atrypa* of the brachiopods and *Modiomorpha, Sphenotus,* and *Cypricardella* of the pelecypods. In a long list of Devonian forms the few Mississippian elements are *Syringothyris* (not always Mississippian), *Spirifer marionensis,* and *goniatites.* Total absence of true productids is significant. At present the fossils have not been sufficiently well studied or illustrated to date the beds definitely. Should the fauna prove to be Devonian the black shales will be Devonian; but if its age remains Mississippian, as it is by definition, the lower Kinderhook being part of the type Mississippian, the fauna will serve as an excellent ceiling for the Upper Devonian.

In the South the age of the Chattanooga has been scrutinized by J. H. Swartz (1924) who describes a section near Apison, 16 miles east of Chattanooga. Above 10 feet of black shale in this section about 2 feet of dark-gray shale contained *Lingula irvinensis, Rhipidomella, Chonetes acutiliratus, Schuchertella,* and *rhynchonellids* which identify it with the Bedford-Berea wedge. Above this layer *Lingula melie* indicates the Sunbury shale. According to Swartz the shale below the Bedford-Berea is of Cleveland age, here assigned to the Devonian. In the Big Stone Gap region Swartz (1929) shows the Big Stone Gap shale of Stose to be divisible into the Cumberland Gap shale at the base, the Olinger shale,

and the Big Stone Gap shale, restricted, at the top. The Olinger contains a fauna suggestive of the Hamburg. These shales have been correlated with the Chattanooga, and Swartz concludes that the Chattanooga shale in Tennessee and Virginia is Mississippian "with the possible exception of the lower part of the Cumberland Gap member." Inasmuch as this member interfingers with the Olinger it is contemporaneous with it.

In Oklahoma, Missouri, Mississippi, and Arkansas thin black shale formations occur that have been loosely called Chattanooga. Those containing the *Schizobolus* fauna are definitely Devonian and probably are more accurately called Trousdale, the Geneseo black shale of Tennessee. The other black shales called Chattanooga may be the feather edge of the Upper Devonian, but the point cannot be proved. In Alabama the writer has identified *Lingulipora*, a Geneseo brachiopod, in greenish rocks associated with the black shale and previously called Chattanooga.

In summary it may be said that according to the writer's view most of the black shale discussed in the Midwest and Appalachian region represents a black shale facies of the Upper Devonian underlying a fauna of highest Upper Devonian or basal Kinderhookian age. These black shales may represent the feather edge of the thinning Upper Devonian, thickening locally on the flank of the Cincinnati arch as shown by Caster (1934) in the case of the Cleveland shale. Furthermore the Bedford-Hamburg shows a facies change in harmony with that of the Devonian—*i. e.* shale in Ohio and Indiana and limestone in Illinois and Missouri.

IMPORTANT NEW CHANGES IN CORRELATION

For emphasis the important changes in Devonian correlation and thought proposed in the chart and accompanying text are as follows:

(1) Grouping of the Devonian into 10 stages.

(2) Assignment of Heppel, Causapscal, and Gaspe formations to the lower Onesquethaw stage rather than to the Hamilton and Naples groups.

(3) Assignment of the Tully and Geneseo formations to the Middle Devonian, Taghanic stage.

(4) Correlation of the upper Traverse of Michigan with the Tully and Cedar Valley formations.

(5) Fixing of all formations correlating with parts of the Hamilton group in the Mississippi Valley as Centerfield or older.

(6) Correlation of the Logansport limestone of Indiana with the Hamilton Beechwood and Four Mile Dam limestones rather than with the Jeffersonville.

(7) Correlation of the Lake Church of Wisconsin and the Abitibi River limestone of James Bay with the Delaware-Rogers City limestone of Presque Isle County, Michigan.

(8) Assignment of the *Paraspirifer* zone of the Silica shale to the Marcellus and the upper Silica to the Ferron Point-Genshaw formations.

(9) Determination of the Mount Marion of the Catskill region, New York, as a partial equivalent of the Chittenango; placing the Ashokan in the Marcellus; correlation of the Bakoven with the Union Springs and the Stony Hollow member with the Cherry Valley limestone.

(10) Placing of Percha shale high in Conewango stage.

(11) Assignment of the Jefferson formation and equivalents to Finger Lakes and Chemung stages.

(12) Recognition of Shell Rock elements in lower Devils Gate formation.

DISCUSSION OF FORMATIONS

NAMES NOT APPEARING ON CHART

Not all valid names appear on the chart; many are too local to be fitted in. Others are so isolated from main sections as to require too many additional columns thus making the chart too unwieldy. For completeness the more important of these names are listed below. These are arranged by the States in which they occur, and their major features can be determined by reference to the *Lexicon of geologic names of the United States* (Witmarth, 1938). It is not claimed that these names plus those appearing on the chart include all Devonian formation names. Synonyms are not included, but some of the names in the list and on the chart may ultimately prove to be synonyms. Named igneous and subsurface formations assigned to the Devonian in general do not appear on the chart or in the list.

During the preparation of the chart it became apparent that many formations were incorrectly correlated. The writer believes that in reassigning these formations it is essential to give the reasons for the shifts. Too many charts with new and far-reaching correlations unsupported by proof have been published and have resulted in no end of confusion. Consequently all new changes on the chart are explained. In some instances the reasons given may not satisfy the reader or other Devonian students; nevertheless the evidence, good or bad, is given. To keep the length of these notes within reasonable bounds information relating to lithology, thickness, and the like has not been repeated; this information can be obtained from the *Lexicon*. Very little information pertaining to

paleontologic evidence for correlations is given in the *Lexicon;* therefore the writer's remarks contain mostly paleontological information.

Alaska
- Takotna
- Vallenar
- Tonzona

Arizona
- Morenci
- Sycamore Creek
- Temple Butte—Chemung or Canadaway

Canada
- Camp Creek
- Famine (see text)
- Horn River
- Knoydart
- Mount Charles
- Nictaux

Illinois
- Hoing (subsurface)

Indiana
- New Chapel chert (in Silver Creek formation)

Iowa
- Montpelier
- Raymond Quarry

Kansas
- Ediger (subsurface)

Maine
- Mapleton

Maryland
- Avilton

Massachusetts
- Vernon

Missouri
- Auxvasse Creek
- Noel

Montana (all Upper Devonian)
- Ermont
- Monarch
- Union

Nevada
- Combs
- Lamoureux

New York (all Upper Devonian)
- Barryville
- Keuka
- Long Beards Riffs
- Mount Herman
- Pope Hollow
- Tunangwant
- Wittenberg

Ohio
- Bellepoint
- Delhi
- Dublin
- Eversole
- Hillsboro (see Detroit River)
- Klondike
- Marblehead
- Venice
- West Jefferson

Oregon
- May Creek

Pennsylvania
- Armenia
- Bimber Run
- Cascade
- Coudersport
- Dutchmans
- Franklindale
- Hosmer Run
- Kingsley
- Lanesboro
- Luthers Mills
- Millers
- New Milford
- North Warren
- Piney Ridge
- Roystone
- Saxton

Tennessee
- Hilton
- Swan Creek

Washington
- Orcas (see text)

West Virginia
- Rowlesburg
- Saxton

EXPLANATION OF CHART

In using the chart the reader must bear in mind the limitations of portraying correlation by this means. In the first place, many of the columns represent sections along meridians rather than at the place named. For example, the Canandaigua Lake column includes more names than those representing rocks appearing on the shores of the lake, the additional ones occurring some distance to the south. Secondly, relative thicknesses are not represented by the size of the compartments separating stages and formations. The space allotted to the stages was arbitrarily planned, and the space assigned to formations in general depends on the number of names appearing in the compartment. The column for Matapedia, Quebec, illustrates the point. The Causapscal, Heppel, and Four Mile Brook formations aggregate several thousand feet, yet they are believed to belong in the Onesquethaw stage of New York which includes a thickness of less than 500 feet of rock.

In a few instances columns are composites of the Devonian formations appearing in a State or region. The formations are arranged according to their position relative to the standard column although they may not appear in continuous sequence in the field. This is true of the column representing the Brisco Range and Windermere District.

In many instances correlations indicated are only suggestive. The Jefferson limestone of northwestern Montana now known to be Upper Devonian is divided into five members as shown by its fossiliferous middle member and is correlated with the New York Chemung. The members above and below the Coopers Lake limestone are also assigned to the Upper Devonian but without conclusive paleontologic evidence. This sort of difficulty also arises in the correlation of units in two separate regions, the limiting members being definitely correlated but the inner members of uncertain affinities. In such an instance the inner members are accommodated to the available space, and definite correlation not indicated. An example is the Ithaca formation of New York consisting of six members of uncertain relationships.

At the extreme left of the chart the ranges of some important fossils are given to help the reader understand the correlations. In general the attempt was made to record the ranges of genera mentioned in the text or those sufficiently restricted and easily recognized to make short segments of the column readily identified.

Abitibi River formation.—Redefined by Kindle (1924) to eliminate the beds containing *Hypothyridina* (now called Williams Island limestone) about 8 feet thick. As thus redefined this limestone is regarded as of Delaware and Rogers City age because recorded lists of fossils show no species entirely restricted to the Onondaga where the formation had been hitherto placed. The species *Gypidula comis, Martinia subumbona,* and *Delthyris consobrina* (possibly *Spirifer lucasensis*) listed by M. Y. Williams (1920) are unusual in or absent from the Onondaga but are common Delaware or Rogers City fossils. *Schizophoria* and *Athyris,* common in the Abitibi River limestone, are present in Onondaga rocks but more abundant in the Delaware. None of the species listed by Savage and Van Tuyl (1919) from the Abitibi River lends any support to their suggested correlation with the late Devonian of Iowa.

Alpena limestone (A. S. Warthin and G. A. Cooper).—Further restriction of this name is necessary after more detailed studies by the authors. The lower 15 feet contains a Genshaw fauna and has been placed with that formation. The next division, called Newton Creek limestone, consists of 25 feet of yellowish to brown crystalline limestone containing oil in cavities and fossils. Large numbers of *Pentamerella, Camerophoria,*

Charionella, Cranaena, and color-banded cephalopods are present. The succeeding limestone, to which the name Alpena is restricted, consists of 79 feet of light-gray to white limestone. In the upper 40 feet large bioherms of *Prismatophyllum* and *Stromatopora* are conspicuous. Above the Alpena (restricted) occur 8 feet of blue clay shale, the Dock Street Clay of Grabau (1902), a lens confined to the east side of Alpena, and classified with the Alpena limestone. Overlying the Dock Street and the Alpena and faunally related to them is the Four Mile Dam limestone, 8 feet thick at the south end of the quarry of the Thunder Bay Quarries Company. The type section is at Four Mile Dam where the formation is represented by a bioherm containing many elements of the Centerfield fauna of New York.

Alto formation.—Correlated with the Cornell and Sherburne formations of New York because of the reported presence of *"Reticularia" laevis* (Hall) (*see* Savage, 1920.), but may actually belong in the Taghanic stage because of indicated Tully affinities (Savage *in* Jillson, 1931).

Amherstburg dolomite.—One member of the Detroit River series containing among other Onondaga types *"Spirifer" divaricatus* Hall pointing to a position in the lower part of the Onondaga (Schoharie?). (*See* Detroit River.)

Amity shale.—Low in the Conewango group of Chadwick. Contains the peculiar spiriferoid *"Cyrtia" alta* Hall which also occurs in the lower part of the Chagrin shale of Ohio. *"Cyrtia" alta* does not belong to *Cyrtia,* a Silurian genus, because it differs in the structure of the beak, apical plate, form of the valves, and ornamentation. The Silurian *Cyrtia* possesses a perforate arched deltidium, whereas that of *"Cyrtia" alta* is an imperforate plate not arched above the interarea and is thus like that of *Syringothyris. "Cyrtia" alta* belongs to Kindle's genus *Syringospira* (1909, p. 28) from the Percha shale of New Mexico which possesses the extremely elongated ventral palintrope, apical plate and costellate fold and sulcus exactly like the New York and Ohio species. (*See* Percha shale, Ouray limestone.)

Antrim black shale.—In Alpena County, Michigan, the lower part of this shale above the Squaw Bay formation contains *Styliolina* in abundance, and this fossil is also known in the black shale just west of Beebe School, southwest of Afton, Cheboygan County. It has been generally believed for some years that the black shale above the *Styliolina* beds is Mississippian. Against this view is the fact that Devonian fossils have been collected in the great shale pit at Paxton, 8 miles west of Alpena. The writer discovered *Barroisella subspatulata* (Meek and

Worthen) in patches of green shale on the floor of the quarry, and Ehlers (personal communication) and his students collected the goniatite *Tornoceras* in a concretion higher in the quarry. This is a typical Devonian fossil as yet unknown from the Mississippian.

In the supposed Waverleyan beds exposed on the shore of Lake Michigan, a mile north of Norwood, Cooper and Cloud with Ehlers and party found *Styliolina, Paracardium,* and *Buchioloa* in the hard greenish layers at the base of the black shale. These fossils indicate a horizon probably higher than the Squaw Bay limestone, but nevertheless low in the Upper Devonian. The black shale above the *Paracardium* beds contains Devonian conodonts (Ehlers, personal communication).

Arkona shale.—Represents final passage of the dark Levanna shale of New York to a light-colored calcareous shale. Black fingers of Levanna type, containing *Leiorhynchus,* occur near the top of the Arkona. Fossils are most like those of the Chenango sandstone of the New York Hamilton, but some Michigan elements suggestive of the Bell and Ferron Point shales are present.

Ashland limestone.—Rensselandia [*Newberria*] zone of central and northeastern Missouri.

Ashokan sandstone.—Recognized in the Catskill region northeastward from Kingston nearly to Albany and southwestward to the central part of the Rosendale Quadrangle. The Ashokan is for the most part composed of poorly fossiliferous, nonmarine sandstone containing a few plants and fishes. In the Coxsackie Quadrangle marine fossils appear sparingly toward the seaward side of the mass. It overlies the Mount Marion formation of the Marcellus stage which contains abundant *Paraspirifer.* An upper Marcellus age is suggested because the thickness of the Ashokan combined with that of the Mount Marion and Bakoven is about 1300 feet, a thickness about equal that of the Marcellus of the Schoharie Valley (1000 feet) plus the normal increase of thickness expectable between Schoharie Valley and Catskill.

Bakoven shale.—Represents the easternmost known facies of the Union Springs shale. In Cayuga Lake region the Union Springs is a black limestone, but in eastern central New York it is a sooty black shale. In the Catskill region the Union Springs has become a dark sandy shale abounding in *Paracardium* and *Buchiola.*

Bear River formation.—As some uncertainty exists regarding this formation the original description is reproduced:

". . . The only marine Devonian known to date in Nova Scotia is found in Annapolis county in the vicinity of Bear River and Nictaux where it consists for

the most part of dark gray and green and brown shales or reddish sandstone or arenaceous limestone, considerably squeezed and altered, constituting the *Bear River* formation. *Pleurodictyum problematicum* is one of the characteristic species of this horizon which is evidently lower or Eo-Devonian. . . ." (Ami, 1900, p. 206-207).

Beartooth Butte formation.—Placed in the Oriskany-lower Onondaga (=Schoharie) position opposite that portion of the Nevada limestone, the only other known lower Devonian of the West.

Beauvais sandstone.—Fossils such as *Leptaena rhomboidalis, Schizophoria striatula, Spirifer varicosus, Paracyclas elliptica,* and *Proetus* cf. *P. haldemani* reported by Croneis and Hoffman (1931) suggest relationship to the Silver Creek limestone of Indiana. In addition to these fossils poor impressions of the brachiopod *Rensselandia claypolei* (so-called) have been taken. The presence of this genus indicates a Middle Devonian age. The Beauvais lies between a possible Delaware equivalent, the upper Grand Tower, and a probable Skaneateles equivalent, the St. Laurent limestone. The formation has therefore been placed as a facies of the St. Laurent and a possible correlate of the Rogers City limestone which contains *Rensselandia* and occurs in the same position between the Delaware and the Skaneateles.

J. M. Weller (1939) suggested correlation of the Beauvais with the Dutch Creek sandstone because they are lithologically alike, but the two are totally unlike in fauna, and the writer therefore regards the correlation as wholly untenable.

Bedford shale.—Contains a fauna which, according to Caster's lists (1934, p. 158-164), the writer correlates with the fauna of the Hamburg oölite of Illinois, the Glen Park limestone of Missouri, and the marine fauna at the top of the New Albany (Huddle, 1933). The age of the Bedford and its correlates has not yet been settled, a number of geologists regarding it as Devonian, while others hold it to be Mississippian. The date of the formation cannot be settled here; nevertheless it can be stated that this fauna is widely distributed and occurs very close to the Devonian-Mississippian boundary and is the suggested upper limit for the Devonian on the chart.

Beechwood limestone.—Contains the chief elements of the Centerfield fauna of New York: *Pentagonia biplicata, Camerophoria, Camarospira, Cyclorhina, Centronella, Vitulina,* and *Eleutherocrinus cassedayi* (Cooper and Warthin, 1942).

Bell shale (Warthin and Cooper).—Hitherto classified with the Marcellus, this shale lies on the deeply eroded surface of the Rogers City limestone which contains the *Stringocephalus* fauna. Because the Rogers

City overlies the Delaware formation of the Marcellus and underlies a Centerfield equivalent, the Bell is proved to be of early Skaneateles age.

Bellvale sandstone.—According to Willard (1937, p. 271-272) this sandstone contains a Hamilton fauna that correlates with the Marcellus because the formation overlies the Cornwall shale of Onondaga age. Presence of Portage equivalents is most unlikely. (*See* Cornwall shale.)

Bernardston formation.—Most students of this formation agree to a Devonian age of at least part of it. Whitfield (1883, p. 368) suggested a Silurian age for the lower limestone and a probable Middle Devonian age for the overlying sandstone. Clarke (*in* Emerson, 1898, p. 259) on the other hand stated a late Devonian age for the shaly quartzites.

According to Emerson (1898, p. 264, Fig. 17) the fossiliferous rocks consist of limestone containing *Favosites*, cyathophylloids, and large and small crinoid stems. Over this lies a bed of magnetite up to 3½ feet thick on which occurs a calcareous sandstone containing much distorted impressions of fossils. The writer saw no identifiable specimens from this sandstone.

Clarke's contention that these beds are late Devonian is untenable because: (1) According to present views, all late Devonian rocks are absent or of an entirely nonmarine facies on the Catskill Front, precluding the presence of marine Upper Devonian on the east side of the Hudson Valley. The main mass of the Catskill Front is now known to be of Hamilton and Taghanic age. The known marine Devonian that extends across the Hudson Valley ranges from Helderberg (Coeymans) to Onondaga. It is among these formations that one would expect to find relations with the Bernardston beds. (2) New fossil evidence in the form of a fairly well preserved "*Spirifer*" from the magnetite bed gives evidence for an Onondaga age. This "*Spirifer*" is of an unusual type now known only in Onondaga and Hamilton rocks, and the specimen itself is not wholly typical of the group to which it is here assigned. It is a completely costate *Spirifer* such as *S. venustus* and *S. divaricatus*. Because the specimen is an impression of the interior none of the finer ornamentation is preserved. This ornamentation is important in the definition of the genus and consists of zigzag concentric lamellae bearing a row of fine spines on the edges. The Bernardston specimen is most suggestive of *S. divaricatus* or *S. grieri* because of its strong costae but differs in showing no divarication of the ribs at their anterior ends.

Boule limestone.—Raymond (1930, p. 294-296, 300) applied this name to his zones 3 and 4 of the Roche Miette section. Zone 3 contains *Ambothyris* ("non-plicate *Cyrtina*") and *Gruenwaldtia* ("small *Atrypa*")

like those of the Independence shale of Iowa and the "Percha" shale of the Sacramento Mountains of New Mexico.

Brallier shale.—In southwestern Virginia fingers of black shale have been detected in the Brallier which, according to Butts (personal communication) represent the appearance of the Big Stone Gap shale (of Stose). The latter has been correlated with the Chattanooga at its type locality.

Caballos novaculite.—Aberdeen (1938) studied the radiolarian fauna of this formation and stated that two of the species showed a "slight similarity to radiolaria described from the Tamworth series (Devonian) of Australia." Correlated with Camden and lower Arkansas mainly on lithology.

Callaway limestone.—Correlated with the upper part of the Cedar Valley limestone—upper Rapid, *Atrypa waterlooensis* zone to Coralville—following Branson (1924, p. 2) and Stainbrook (1935a, p. 260). Correlation based on abundance of *Cranaena*, presence of *Camerophoria gregeri* (Branson), large *Schizophoria*, and *Syringothyris*-like spiriferoids. The sandstone at the top of the Cedar Valley in Calhoun County, Illinois, contains Callaway types.

Camden chert.—Until now the Camden fauna has been recognized outside of Tennessee only in the Clear Creek chert of Illinois, but published lists and collections studied by the writer from the Southern Appalachians and West Virginia indicate that the Camden fauna is more widely distributed than hitherto believed. The fauna of the Huntersville chert and most of the so-called Onondaga of the South is of Camden age. The Camden itself is correlated with the Schoharie as explained below.

Canadaway group (extracted from G. H. Chadwick letter to Cooper, Jan. 25, 1941).—Changes are imminent that will invalidate Canadaway and Conneaut or require their redefinition, with probably another group introduced between them. The former correlation was:

	Lake Erie	Genesee-Olean
Conneaut	Chadakoin ("Chemung pink")	Haymaker (Chadakoin "pink")
		Hinsdale
	Volusia (Girard of NW. Pa.)	Cadiz (Volusia)
		Cuba
Canadaway	Northeast	Machias
	Shumla	
	Westfield	Rushford
	Laona	
	Gowanda	Canadea (Gowanda)
	Dunkirk	Dunkirk (Canaseraga)

The Gowanda undoubtedly includes more than the Caneadea, and there is reason to believe that the Cuba is the Laona, a correlation indicating identity of Hinsdale and Shumla. The Haymaker should then be equivalent to part, though probably not all, of the Northeast shale. In fact the Cattaraugus as well as the Haymaker may correlate with the Northeast shale.

The Canadaway paleontologically should terminate upward at the base of the Cuba sandstone. A similar sharp faunal break comes at the base of the Laona sandstone. If the Cuba and Laona are identical, as now seems likely, then the group from the Cuba up through at least the Haymaker is not Conneaut which is defined in eastern Ohio where it includes the Girard and Chadakoin only. Chadwick suggests limiting the Canadaway to the Dunkirk and Gowanda and introducing a new group name for the beds between the Canadaway and Conneaut, as follows:

	Lake Erie	Genesee-Olean
Conneaut group	Chadakoin Girard	
Unnamed group	Northeast Shumla Westfield Laona	Haymaker Hinsdale Cadiz Cuba
Canadaway group	Gowanda Dunkirk	Caneadea Dunkirk

Canutillo formation.—Named by L. A. Nelson (1937) for black shale, sandstone, and gray limestone in the Franklin Mountains north of El Paso, Texas. This formation is assigned to the middle Devonian (Nelson, 1940).

A collection of fossils from opposite Vinton, Texas, sent to Dr. G. H. Girty and now in the National Museum contains the brachiopods *Schizobolus, Meristella, Mucrospirifer,* and *Leiorhynchus.* The presence of *Schizobolus* suggests correlation with the Geneseo shale of New York, the Trousdale shale of Tennessee and Arkansas, and the lower 10 feet of the New Albany shale of Indiana. This correlation, however, must be regarded as tentative because the complete fauna of the Canutillo formation has not been published. Moreover the possibility of the Canutillo formation equaling part of the Sly Gap formation should not be overlooked. The Sly Gap contains *Leiorhynchus* according to Stainbrook (1935b) and Laudon and Bowsher (1941) in a black shale. It is thus possible that the Sly Gap includes the Canutillo.

Cap Barré limestone.—Dated as New Scotland by the presence of the strange trilobite *Dicranurus limenarcha* Clarke, although a possible Coeymans age should not be overlooked. Alcock (1935, p. 67) includes

this limestone in the Murailles formation because it cannot be recognized west of the coast.

Cap Bon Ami limestone.—Contains a few Helderberg species. Overlies the St. Albans formation of New Scotland age and underlies the Grande Grêve limestone of Oriskany age. Therefore tentatively assigned to the Becraft and correlated with the Dalhousie formation.

Causapscal formation.—Crickmay (1932, p. 376) suggests a correlation with the Grande Grêve limestone of Gaspe. The presence of *Eodevonaria, Leptocoelia,* and *Spirifer* cf. *S. modestus* are suggestive of the Schoharie and the Camden chert.

Cedar Valley limestone (Cooper and Warthin).—The age of the Cedar Valley has long been a moot question. The presence of *Hypothyridina* in the lower Cedar Valley led Thomas (1924, p. 408) and Weller (1909, p. 265-266) to correlate it with the Tully of New York and place the formation in the Upper Devonian. Stainbrook (1935a, p. 255) on the other hand believes the Cedar Valley is late Devonian because a Chemung fauna, the Independence shale fauna, underlies it.

Hypothyridina has long been a misleading fossil (*see Hypothyridina*); its supposed basal Upper Devonian position has been accepted almost without question in this country, and the presence of the genus has been used to outweigh all other evidence. Actually it occurs well down in the Middle Devonian in Europe and Asia; consequently its mere presence does not signify an Upper Devonian age.

The known fauna of the Cedar Valley contains no fossils of unequivocal late Devonian age. Not only are late Devonian guides absent, but the majority of the genera are those most commonly found in Onondaga to Tully strata, such as *Stropheodonta, Pentamerella, Leptostrophia, Megistrocrinus, Stereocrinus, Pentremitidea, Nucleocrinus,* and *Prismatophyllum.* Although some of these genera are also known in the Upper Devonian, they are most abundant in Middle Devonian rocks, and often their species make up a large percentage of the fauna. The following Cedar Valley genera are unknown from late Devonian rocks: *Rensselandia, Charionella, Billingsastraea,* and *Nucleocrinus.* The predominant aspect of the Cedar Valley fauna is that of the Middle Devonian. Significant late Devonian elements absent from the Cedar Valley are: *Cyrtospirifer, Manticoceras, Ambothyris, Strophonelloides, Pugnoides.*

The evidence for the age of the Cedar Valley based on the position of the Independence shale also leads to difficulties. This shale contains an undoubted Chemung fauna, but Stainbrook (1935a, p. 252) believes it to be stratigraphically below the Cedar Valley. Savage (1920, p. 179-180) believes that the Independence represents fillings of caverns in

the Cedar Valley limestone and is therefore younger than the formation it seemingly underlies. Outcrops of the Independence are few, small, and scattered, and all those seen by the writers afforded evidence so equivocal that its postulated position below the Cedar Valley is doubted.

To emphasize the Middle Devonian age of the Cedar Valley it is important to recall that Stainbrook (1935a, p. 260) has already correlated it with unquestionable Middle Devonian rocks. According to him "The Cedar Valley is faunally related to the upper part of the Traverse beds as developed at Partridge Point and probably is of the same age." The beds at Partridge Point (Thunder Bay formation) underlie the Squaw Bay limestone of earliest Genesee age (containing the goniatite *Koenenites*) and correlated with the Genundewa limestone (basal Upper Devonian) of New York.

Not only the age of the entire Cedar Valley is difficult to establish, but the dating of some of its parts presents problems. At present the Solon or lower member is linked with the main body of the formation by the common presence of the unusual crinoid *Stereocrinus*. Cooper and Cloud (1938) suggested the correlation of the Solon (then called Linwood) with the Rogers City limestone (*Stringocephalus* zone) because *Rensselandia* occurred in both. Stainbrook (personal communication) has convinced the writers that the Solon cannot be divorced from the Cedar Valley as a whole.

The Mineola limestone of Missouri and most of the Rapid member of the Cedar Valley fall opposite one another on the chart because of correlation of the overlying Coralville member with the Callaway of Missouri and of the underlying Solon with the *Rensselandia* zone of Missouri. The upper zone of the Rapid formation (*Atrypa waterlooensis* zone) probably should be correlated with part of the Callaway.

Centerfield formation (Cooper and Warthin, 1942).—Contains the most widely distributed known faunal assemblage of the Hamilton, extending across New York and part of Pennsylvania into Ontario, Michigan, Indiana, Ohio, Kentucky, and possibly Illinois and Arkansas. This easily recognized fauna has made subdivision of the Hamilton outside of New York possible and intelligible. The most important genera and species of the Centerfield are: *Favosites turbinatus, Prismatophyllum, Megistocrinus, Dolatocrinus, Eleutherocrinus, Camerophoria, "Spirifer" sculptilis, "S." venustus, Camarospira, Pentagonia biplicata, Cyclorhina nobilis, Parazyga hirsuta, Centronella impressa,* and *Vitulina pustulosa.*

Smith (1935, p. 43) has suggested that the Centerfield formation be placed in the Skaneateles stage because the two are transitional on the Skaneateles Quadrangle, a condition that persists eastward to the east

side of Chenango Valley. In western New York from Canandaigua westward and in Ontario the Centerfield is set off from the underlying shales by a sharp lithologic change, clearly disconformable. It is not impossible for the Centerfield to be transitional to the Skaneateles in the east and disconformable in the western part of the State. Usually in the section from Skaneateles eastward the lower part of the Centerfield contains, or is underlain by, cross-bedded sands that may in themselves represent breaks, or the two may be falsely transitional because of reworking of older Skaneateles sediments. The faunal break with the Skaneateles is as striking in the eastern part of the State as it is in the western part. The writer therefore sees no reason to transfer the Centerfield from its traditional position at the base of the Ludlowville.

Chagrin shale.—Represents westward facies of the Conewango stage including most of the Chadakoin of New York and Pennsylvania. According to Caster (1934, p. 149) some of the divisions of the Conewango sandstones and shales of western Pennsylvania can be identified in northeastern Ohio. The faunas of the Panama-LeBoeuf conglomerate can be recognized by the presence of *Ptychopteria* and *Syringothyris chemungensis*. The Millers Hollow member of the Salamanca can be differentiated by representatives of the genus *Pararca* and a characteristic mutant of *"Spirifer" disjunctus*. The occurrence of *Syringospira alta* indicates the presence of the Amity shale fauna. The Chagrin is terminated by the Riceville-Oswayo shale. The black shale equivalent of the Chagrin according to Prosser (1912, p. 515) is the Huron shale.

Charlevoix limestone (Cooper and Warthin).—Occurs on the shore of Lake Michigan in Emmet and Charlevoix counties between the "Upper blue shale" (zone 6) of the Gravel Point limestone and the base of the Petoskey limestone. The "Upper blue shale" is correlated with the upper Alpena (approximately Dock Street clay) of Alpena County The lower part of the Petoskey limestone at Bayshore is correlated with the Norway Point formation of Alpena County. Thus the Charlevoix occupies the position of the Four Mile Dam limestone and consists of a heterogeneous series of limestones ranging from platy lithographic limestone with green shale partings to limestone with coral and crinoidal debris and oölites. These all suggest near-shore action and accumulation. It is therefore suggested that the Charlevoix may represent a western shore phase of the Four Mile Dam limestone, but no fossils yet discovered support this contention.

Chattanooga shale.—At its type section Swartz (1924) determined the Chattanooga shale to be in part Upper Devonian and in part Lower Mississippian. Here the section consists of about 11 feet of shale: The

lowest 8 feet corresponds to the Cleveland shale; the next overlying 9 inches of mottled shale are assigned to the Bedford-Berea; the next ⅜ inch of black shale is said to be of Sunbury age; over the Sunbury 2 feet 4 inches of hard shale (Glendale) is correlated with the lower Cuyahoga of Ohio. These are long-ranging correlations, to say the least, and are not based on the best of evidence, but if Swartz is correct the main body of the Chattanooga at its type locality is correlated with the Cleveland shale which is here regarded as Devonian. Correlation of these black shales is so difficult that the age of each occurrence must be considered on its own merits. In northeastern Arkansas black shales called Chattanooga contain Middle Devonian or lowest Upper Devonian fossils; these occurrences should be renamed or referred to the Trousdale shale, Geneseo equivalent in West Tennessee.

Clam Bank series.—Schuchert and Dunbar (1934, p. 104-106) describe a series of red clastics exposed along Clam Bank Cove, St. George Peninsula, Newfoundland. These contain a few fossils, among them a Spirifer "that is more like a Devonian than a Silurian form" and *Camarocrinus*, the bulbous holdfast of *Scyphocrinus*. The evidence is certainly not conclusive of a Devonian age for these sediments because *Camarocrinus* is as well known a Silurian form as it is a Devonian one, ranging from the Keyser to New Scotland. The Clam Bank series may be Devonian but it may also be equivalent to the Keyser which is now regarded as Silurian (Swartz, 1939). It may also be equivalent to the *Camarocrinus*-bearing Griffon Cove River formation of Kindle (*which see*) exposed on the north side of the Gaspe Peninsula.

Cleveland shale.—Dark-gray and black shale of probable Devonian age. Underlies the Bedford shale which contains the Hamburg-Glen Park fauna and overlies the Huron shale, probable black shale facies of the Chagrin shale of Conewango age. The Cleveland shale thickens westward. According to Caster (1934, p. 151) its Devonian age is shown by its fossils, and its eastward thinning represents a reversal of the usual east-west encroachment. Caster suggests uplift of the Cincinnati mass as the source of the black shale, the black muds being poured into the sea from the west producing a wedge thinning eastward. As the Cleveland underlies the Bedford its designation as probably Devonian is strengthened.

Clifty limestone.—Purdue and Miser (1916, p. 9) list a few Hamilton species, among them *Tropidoleptus carinatus and "Spirifer" sculptilis.* In addition to the listed forms the writer identified *Vitulina pustulosa* and *Centronella impressa* in the same collection (collection in U. S. Na-

tional Museum, Cooper locality no. 401). These four fossils indicate a correlation with the *Vitulina* zone of the Lingle limestone of Illinois.

Cooper limestone.—Correlation with the Coggon limestone is here suggested. Both contain a small *Emanuella* suggestive of *E. subumbona* of the New York Hamilton and Tully. A large snail, *Turbonopsis providencis* (Brodhead), occurs in the Cooper and is similar to a species in a lithographic limestone at the top of the Potter Farm formation of Michigan. Therefore the Cooper is tentatively placed with the Cedar Valley in the Tully, and equivalence with the Potter Farm is indicated.

Cornwall shale.—Willard (1937, p. 271-272) assigns this shale to the Onondaga, but it may include Bakoven as well (Warthin, personal communication).

Darby limestone.—Doubtful if any Threeforks is present.

Delaware limestone (Cooper and Warthin).—Covers a greater area than hitherto believed. At its type section several zones can be recognized, one of the most important, the *Hadrophyllum d'orbignyi* zone, near the top. This zone can be recognized at the top of the Speeds limestone in Clark County, Indiana. Peoples (1931, p. 435-436) reports this fossil from the Pegram limestone of western central Tennessee.

The upper Columbus limestone of northwestern Ohio and the Dundee of southern Michigan containing *Spirifer lucasensis* Stauffer are regarded as of Delaware age. The lower part of the Dundee of Presque Isle County, Michigan, contains *S. lucasensis* and is assigned to the Delaware.

The coral-reef limestone of Formosa, Ontario, and vicinity has been correlated erroneously with the Onondaga (Pohl, 1930, p. 59), but as it overlies Detroit River dolomite containing *"Spirifer" divaricatus* it is regarded as of Delaware age.

Delphi black shale.—Assigned to the Naples and Chemung because of the presence of three species of *Manticoceras*. Two of these species according to Miller (1938, p. 83, 91, 123) resemble Genundewa forms, while the third, *M. unduloconstrictum*, is more like a Chemung species.

Detroit River group (A. S. Warthin).—As now understood includes the Sylvania sandstone as its basal deposit (Carman, 1936, p. 260). Reaches its maximum thickness of 1000 feet in wells in central part of southern peninsula of Michigan, but the outcrop thickness is usually less than 200 feet.

Wherever the base of the Sylvania is exposed its contact with the underlying rock is disconformable and the disconformity widens on leaving the Michigan basin. In western Lake Erie region the Sylvania lies

on the Bass Island (Upper Silurian) beds, but the unconformity includes at least part of the Lower Devonian, as indicated by Lower Devonian ostracoderms in a pre-Sylvania stream channel. If this unconformity is followed to the farthest limits of the Michigan basin province, the base of the "Sylvania" basal sand will of course rise in the column. This far-out "Sylvania" sand is probably to be found in the Pendleton of Indiana, the Hillsboro sandstone of southern Ohio, and the Springvale sandstone in the region around Cayuga, Ontario. In the first two cases the unconformity beneath the sand is so wide that it rests upon Niagaran limestones. Being younger than the true Sylvania, the Pendleton is overlain by higher (Middle Devonian) beds; the Hillsboro is overlain by the Ohio shale.

The beds covering the Detroit River vary somewhat in age from place to place indicating a disconformity at the top, but not so great as the one at the base. The overlying rocks at Sibley, Michigan, northwestern Ohio, and Amherstburg, Ontario, are of Dundee age; in Bruce and Huron counties, Ontario, the overlying rock is lower Onondaga with *Amphigenia*, except for the reef masses at Formosa and vicinity which are of Delaware age; on Mill Creek, Cheboygan County, Michigan, the Detroit River is said to contain a Schoharie fauna and is overlain by the *Amphigenia*-bearing Mackinac breccia.

Sherzer and Grabau (1910) subdivided the Detroit River in descending order into the Lucas dolomite, Amherstburg dolomite, Anderdon limestone, and Flat Rock dolomite. This succession nowhere crops out in its entirety. In the Oakwood salt shaft at Detroit the Amherstburg is not definitely recognized, although in the Detroit River channel cuts, only 3½ miles away, a thick section of both beds occurs. Two miles east of the channel cuts, at Amherstburg, Ontario, the Lucas and Amherstburg again cannot be recognized. This has led to the belief that the three upper subdivisions of the Detroit River group have either very local and scattered distribution or they are facies of a single formation. The Anderdon limestone may be only a limestone facies of the Lucas (Ehlers, personal communication), and the Amherstburg a dolomitized coralline facies of the same formation. If the Amherstburg and Anderdon are considered facies of the Lucas dolomite no grounds can be found for recognizing the Flat Rock as anything but the lower part of the Lucas beds. Furthermore, part of the Detroit River in Ontario and Ohio may represent dolomitized Onondaga and Columbus limestones.

Devils Gate limestone.—Embraces 2065 feet of limestone lying on the *Stringocephalus* zone of the Nevada limestone, Eureka district, Nevada. The type section is at Devils Gate, 6 miles west-northwest of Eureka.

According to Merriam (1940, p. 16, 25, 59-61) this limestone contains four zones: the lowest, *Stromoatopora* zone, the *Spirifer argentarius* zone, the *Pachyphyllum* zone, and finally the *Cyrtospirifer* zone. The age of the lowest zone cannot be definitely stated, but it is tentatively assigned to the Genesee or lowest group of the Upper Devonian. The *Spirifer argentarius* zone contains *Tenticospirifer utahensis,* a multiplicate spiriferoid of late Devonian type possibly related to *"S." cyrtiniformis* and very close to *"Trigonotreta" shellrockensis* Belanski. On the basis of the spiriferoids the zone is placed low in the Naples group. The *Pachyphyllum* zone contains a species of *Hypothyridina* and *Cyrtospirifer,* a combination relating it to the Independence fauna and the Chemung. The uppermost or *Cyrtospirifer* zone containing *Athyris angelicoides* Merriam is assigned to the Cassadaga (Canadaway group) stage because of its similarity to the New York fauna.

Dock Street clay.—See Alpena limestone.

Dundee limestone.—Bassett (1935, p. 425-462) shows that the type Dundee exposed in the Sibley Quarry, southeastern Michigan, contains *Spirifer lucasensis,* and is underlain by the Anderdon limestone. He correlates this section with the "Upper Columbus" of the Silica and Whitehouse quarries in northwestern Ohio where the Dundee overlies Lucas dolomite and underlies the "Blue bed" of the Silica shale. Thus the Dundee lies between Onondaga dolomite and Hamilton shale. In Presque Isle County, Michigan, the Dundee overlies the Mackinac Breccia of lower Onondaga (Schoharie) age and underlies the Rogers City limestone which carries the *Stringocephalus* fauna.

Dutch Creek sandstone.—Weller's (1939, p. 130) recently suggested correlation of the Dutch Creek and Beauvais sandstones on the basis of lithology is regarded as wholly untenable. *Amphigenia* is abundant in the Dutch Creek but has never been seen in the Beauvais. Moreover, *Rensselandia* is abundant in part of the Beauvais but is unknown from the Dutch Creek. In all known occurrences *Amphigenia* is lower Onondaga, and *Rensselandia* is Hamilton to Tully.

Ellsworth shale (G. M. Ehlers).—Has been placed in the Mississippian because the upper part of the underlying Antrim shale was assigned to the Mississippian by Doctor Ulrich.

Available information suggests that the upper as well as the lower part of the Antrim is Upper Devonian. Dr. Margaret Morse Rainwater, as the result of a study of the conodonts of the Antrim, which soon will be ready for publication, concluded that the conodonts of the upper part of this formation were more closely related to Devonian species than

to species from strata considered of undisputed Mississippian age. The identification of a few cephalopods obtained from the upper part of the Antrim also indicates a Devonian age. Professor A. K. Miller, who identified the cephalopods for Doctor Rainwater as *Tornoceras* sp., states that *Tornoceras* never has been found above the Devonian and not even in the highest Devonian of this country and Europe.

If the Antrim is Upper Devonian, the Ellsworth shale also may be of this age. No one, so far as I know, has collected any fossils from the Ellsworth which definitely prove its geologic age. An abundance of *Sporangites* in the Ellsworth and Antrim shales and an interfingering of these shales as indicated from the examination of well samples by petroleum geologists suggest, however, that the two formations do not differ greatly in age. From the evidence available I believe the Ellsworth and Antrim shales should be placed in the Upper Devonian rather than in the Mississippian.

The relationship of the Ellsworth shale, which is present in the western half of the Southern Peninsula, to the so-called Bedford, Berea, and Sunbury formations of eastern Michigan is not settled. Records of deep wells in eastern Michigan given by petroleum and other geologists indicate that the "Bedford" rests on the Antrim shale and that the Coldwater shale lies on the "Sunbury shale" or "Berea sandstone" where the former is absent. Well records in western Michigan show the Coldwater directly on the Ellsworth shale. The fact that the Coldwater shale rests on different strata in passing from the eastern to the western part of the Southern Peninsula suggests that a systemic boundary may be present at the base of the Coldwater. The finding and identification of fossils in cuttings from deep wells would aid materially in the recognition of the boundary, the presence or absence of an overlap, and especially the stratigraphic relationship of the Ellsworth.

I have never admitted that the "Bedford", "Berea" and "Sunbury" of Michigan are the equivalent of the formations in Ohio having these names. The Michigan formations are on the western side of the Cincinnati geanticline in a different basin of deposition from that of the typical Ohio formations which are on the eastern side of this structure about 200 miles distant. I think it is quite possible the "Bedford", "Berea", and "Sunbury" of Michigan may be Devonian. A comparison of stratigraphic positions (which may be apparent rather than real) and of thickness indicates that these formations are equivalent to some part of the Ellsworth which I should place in the Devonian.

The Coldwater shale and the succeeding Marshall Group undoubtedly are Mississippian. The Coldwater is the first, apparently the lowest, formation, we can say is definitely Mississippian age. Some distance up

in the Marshall occurs a fauna with many goniatites identical with species found in the Rockford limestone of Indiana. The stratigraphic tie-up thus indicated means that we have a very large Kinderhook section in Michigan, most of which, unfortunately, is covered by drift.

Elm Point limestone.—Buff limestone about 20 feet thick containing a small fauna which Kindle (1914, p. 251) listed, including a fine-ribbed *Atrypa* with prominent marginal frill and the snail *Büchelia tyrrelli* (Whiteaves). This fine-ribbed, frilled *Atrypa* is common in the Rogers City limestone of Michigan and occurs with the same snail. The presence of *Büchelia tyrrelli* in the Manitoba limestone as well as the Elm Point shows that all three limestones of Manitoba—the Elm Point, Winnepegosis, and Manitoba—are not to be dissociated.

Enfield formation.—As represented on the chart this formation lies between the Ithaca and Chemung and, according to Chadwick (1935, p. 858), is the eastern representative of the Rhinestreet-Hatch sequence. A correlation varying considerably from that on the chart was published in abstract form by Caster (1933, p. 201, 202) who claims that the Enfield of the Ithaca region consists of the Van Etten and Hatch, the former "presumably" of Wiscoy age and including the First *Tropidoleptus* zone at its base. Inasmuch as the Wiscoy is generally represented as overlying the Nunda sandstone (High Point) high in the Chemung, Caster's view is in serious conflict with Chadwick's.

Escuminac formation (William L. Bryant).—The following information was furnished by Bryant after request by Cooper to analyze the list of Escuminac fishes given by Alcock (1935, p. 88).

"The genera *Fleurantia* and *Euphanerops* are known only from Scaumenac Bay. *Scaumenacia* is also known from the Upper Old Red Sandstone. *Bothriolepis* is a typically Upper Devonian fish, as is *Eusthenopteron* (also found in Europe). *Cephalaspis* ranges from the Upper Silurian to the Upper Devonian; *Cheirolepis* from the Middle to the Upper Devonian; *Coccosteus* mostly from the Upper Devonian though it is also known from the Middle Devonian. *Diplicanthus* is found from the Upper Silurian to the Upper Devonian. *Holoptychius* occurs both in the Middle and Upper Devonian. The *Acanthodians* are known from the Lower Devonian to the Permian. Westoll and Graham-Smith were here last year and . . . In a general way they consider the deposits of Scaumenac Bay to be of *Early* Upper Devonian Age, and in that I agree."

Esopus shale.—Hitherto classified as the upper member of the Oriskany, has been transferred by Willard (1939, p. 145) to the Onesquethaw stage because of transition between the two in eastern New York and Pennsylvania. The upward transition of the Esopus into the overlying formation is not with the Onondaga but with the Schoharie which has been mistaken for Onondaga. The fauna reported as belonging to the Esopus is actually a calcareous-shaly facies of the Schoharie as shown

below by Goldring and Flower. The upper transition zone links the Esopus to the Schoharie-Onondaga, and it has been so placed on the chart.

Exshaw shale.—In the Canadian Rockies, consists of dark shale between the Mississippian Banff limestone and the Minnewanka limestone containing *Cyrtospirifer*. Contains *Camarotoechia nordeggi, Cyrtospirifer "whitneyi", "Spirifer" raymondi, Athyris "angelica"*, and *Tornoceras* (Warren, 1937, p. 454). *Tornoceras* indicates the Devonian age of the formation, and the other species suggest correlation with the Threeforks shale and the shaly part of the Milligen formation of Idaho.

Famine series.—Located east and northeast of the junction of the Famine and Chaudiere rivers south-southeast of Quebec. Consists of a basal conglomerate, intermediate shaly limestone, and an overlying shale, all occupying a belt about 1500 feet wide. The limestone contains fossils including the following: *Leptocoelia flabellites, Spirifer gregarius* [?], *Chonetes arcuata, Stropheodonta, Pterinea textilis*, and *Paracyclas*, which suggest a correlation with the upper Grande Grêve limestone.

Fourmile Brook shale.—Is about 600 feet thick and was named by Kindle (1938, p. 39) to distinguish the upper part of Alcock's Heppel sandstone. Kindle correlates this shale with the Ithaca of New York primarily on the presence of the brachiopod *Spirifer pennatus posterus* Hall and Clarke, which, in New York and the Appalachians, is common in the lower part of the sandy facies of Taghanic and Naples groups. Contributory evidence, according to Kindle, is furnished by the presence of *Strophalosia truncata* var. and *Paracyclas lirata*.

Other listed fossils do not support an Ithaca age for this shale. For example, the Lower to Middle Devonian genus *Eodevonaria* is listed. In fact none of the genera recorded is of unequivocal Upper Devonian age. Kindle furnishes no figures of the *Spirifer pennatus posterus;* consequently the correctness of the identification cannot be confirmed. It is an important fact that *Eodevonaria* has not been reported above the Onondaga. The listed species are most suggestive of a Hamilton age, as they are given Hamilton names, but *Eodevonaria* argues for an earlier date. The shaly facies of the Onondaga in Pennsylvania contains many Hamilton species; therefore the Fourmile Brook shale fauna is probably actually an Onondaga fauna normally restricted to the shale facies.

Four Mile Dam limestone (Cooper and Warthin, 1942).—At its type section on Thunder Bay River above Alpena consists of reef limestone containing a fauna with Centerfield elements: *Spirifer venustus, Cyclorhina, Camarospira, Camerophoria, Parazyga, Nucleocrinus, Strombodes*

alpenensis. This fauna is also known from a few feet of gray limestone overlying the Dock Street clay in the southeast side of the quarry of the Thunder Bay Quarries Company, Alpena, Michigan. This limestone furnishes the most definite link between Michigan and Ontario as it correlates with the Hungry Hollow formation.

Gaspe sandstone.—Age hitherto variously stated between the Oriskany and the Hamilton, but recently Kindle (1938, p. 41, 44) suggested an Upper Devonian ("Portage") age for the upper part of the Gaspe (Sonneau Brook beds-Fourmile Brook shale) sandstone. For the lower part of York River sandstone Kindle suggests a Hamilton age, mainly on the basis of Mollusca. Kindle correctly indicates that the Gaspe differs strongly in facies from the underlying Grande Grêve limestone which contains a related fauna, but the writer believes the Gaspe fauna to be an Onondaga fauna—a sandstone facies of the Onondaga.

The known fauna of the Gaspe sandstone comprises 16 brachiopods, 25 pelecypods, 12 gastropods, and about 16 species from other phyla. According to Kindle seven brachiopods, *Eodevonaria gaspensis, Chonostrophia dawsoni, Spirifer gaspensis, Leptocoelia flabellites, Eatonia peculiaris, Rensselaeria gaspensis,* and *Chonetes billingsi,* are holdovers from the Grande Grêve fauna and, as relicts, have no correlative value. Twenty-three species or one-third of the fauna are closely allied to Hamilton forms, mostly long-ranging generalized Mollusca such as *Leda (Nuculana), Paracyclas, Nuculites, Schizodus, Sphenotus, Modiella, Grammysia,* and *"Actinopteria"*. The poor preservation of molluscs in the Gaspe sandstone makes these forms very difficult to identify with known Hamilton species and makes questionable many of the specific determinations recorded. The writer therefore believes that the suggested correlation places the Gaspe fauna too high in the Devonian for the following reasons:

(1) The so-called relict forms are numerically the most abundant in individuals, far outnumbering the supposed advanced types. *Chonostrophia* reaches its greatest size in this formation.

(2) The pelecypods are genera chiefly restricted to sandstone and are found in any arenaceous facies from the high Helderberg through the remainder of the Devonian. They are facies fossils, and therefore their correlative value should be discounted.

(3) The sandy equivalents of the Upper Grande Grêve faunas are not known. In the Appalachians where the Onondaga is shaly or sandy, the same types of clams appear as in the Gaspe sandstone (Kindle, 1912). Furthermore the so-called *Actinopteria* or *Pterinea* of the Gaspe sandstone is a type not yet reported from the Hamilton (group of *P. com-*

munis) but is common in the Helderberg and Onondaga. From the above arguments the writer believes that the Gaspe sandstone is of Schoharie (Camden chert) age.

Geneseo shale.—Assigned to the Taghanic stage. In the Cayuga Lake region thin limestones in the base of the Geneseo indicate a persistence of Tully deposition although the base of the Geneseo to the west is disconformable on the Tully. Some of the most important elements of the Geneseo such as *Schizobolus truncatus* and *Buchiola* appear in the Hamilton. Furthermore the Tully fossil *Hypothyridina venustula* occurs in the black shale of eastern Kentucky hitherto regarded as Geneseo, thus supplying a faunal as well as a lithologic link to the Tully. The writer found *H. venustula* in the collection of fossils made by G. H. Girty at Oil Springs on Lulbegrud Creek, 2 miles southeast of Indian Fields, Clark County, Kentucky. This collection came from the *Lingulipora* zone of the Geneseo and points either to a Tully age for the Geneseo or a greater range of *Hypothyridina venustula*.

The most important reason for assigning the Geneseo to the Tully stage is the postulated presence of a disconformity at the top between Lake Erie and Seneca Lake. Over this distance the Genundewa or *Styliolina* limestone overlies the Geneseo and is composed almost wholly of tiny shells of the pteropod *Styliolina*. Accumulation of this limestone, even though it is only a foot thick, must have taken considerable time and thus represents a distinct break in black shale deposition. Not only does the Genundewa represent a break in prevailing sedimentation, it actually contains many new faunal elements—those of the *Manticoceras* zone. It is in the Genundewa limestone that all but one of the goniatites assigned to the "Genesee" shale appears; it is at this level that the Naples fauna becomes established.

In Kentucky and the Midwest to eastern Arkansas and Texas a representative of the Geneseo is known in the form of black shale containing the brachiopod *Schizobolus*. In Michigan and Iowa the Thunder Bay and Cedar Valley formations are possible correlates of the Geneseo but at present seem best placed with the Tully limestone.

Geneva dolomite.—According to Sutton and Sutton (1937, p. 331)

> "The Geneva [of southern Indiana] is a northward lithologic facies of the Jeffersonville formation of Onondaga age as shown by the Onondaga faunules of the Jeffersonville which continue into the Geneva at the same horizons and by the lateral transition from the dolomitic Geneva limestone to the purer Jeffersonville limestone. This gradation begins farthest south in the lowest beds and reaches the progressively higher beds toward the north, which makes it appear on casual investigation that the Jeffersonville thins toward the north, the thinning being accompanied by a corresponding thickening of the Geneva."

Campbell (1942) strongly dissents from this view and claims that the Geneva is always distinguishable from the Jeffersonville.

Genshaw limestone (Warthin and Cooper).—Originally proposed (Warthin and Cooper, 1935, p. 526) for the thin limestones and shales between the Ferron Point formation and the Killians limestone. Later work, particularly in Presque Isle and Cheboygan counties, showed that black limestone of Killians facies appears in the Genshaw. The writers therefore redefine the Genshaw to include the Killians and the lower 15 feet of the Alpena limestone which contains many Genshaw species.

Genundewa limestone.—Represents a break in sedimentation (*see* Geneseo) along the northern shore of the Devonian sea. This break taken in connection with the influx of many new types of fossils is believed to inaugurate the Upper Devonian in New York. West of New York the Squaw Bay limestone is believed to represent the Genundewa and contains the goniatite *Koenenites,* earliest of the Upper Devonian goniatites of Germany.

Glen Park limestone.—For years regarded as Kinderhook in age and correlated with the Hamburg oölite of Illinois. It is suggested here that the Glen Park fauna also correlates with the Bedford of Ohio and the marine fauna at the top of the New Albany shale. Branson and Mehl (1938, p. 157; Branson, 1938, p. 8, Fig. 2) suggest that the Louisiana limestone and Glen Park faunas are actually Devonian. The Bedford, Louisiana, and Glen Park contain many Devonian elements such as *Atrypa, Nucleospira, Productella, "Delthyris", Cypricardella, Sphenotus,* and *Pholadella.* Most of the reported clams and snails are Devonian types. A few Mississippian types appear such as *Spirifer* (*S. marionensis* type) and "Goniatites". *Syringothyris,* often quoted as indicative of the Mississippian, is also a well-established Devonian fossil in southwestern New York and northwestern Pennsylvania. It is not important here to settle the age of the Glen Park and its correlates; it is significant to emphasize the equivocal nature of the fauna and the possibility of its serving as a base of the Mississippian or top of the Devonian when it is finally decided on which side of the line it should be placed. The fairly widespread character of this fauna enhances its value for the purpose suggested.

Grande Grêve limestone.—Clarke (1908, p. 39-46) divided this limestone into three parts, the lower two containing an abundance of Oriskany fossils, while the upper division contains few of these familiar forms. Some who have studied the Grande Grêve limestone see a similarity to the Schoharie, but the writer believes that the entire sequence

is Oriskany. However, in all probability the top division is higher than any Oriskany exposed in New York. The upper division contains such Oriskany forms as *Rensselaeria, Chonostrophia, Eodevonaria, Anoplia, Spirifer arenosus,* and *Eatonia.* Except for the last two these are seen higher in the Gaspe sandstone, and all but *Rensselaeria* and *S. arenosus* are known in the Camden chert. The writer has placed the entire Grande Grêve in the Deerpark stage because no unequivocal Onondaga forms have yet been taken from it, and the higher Gaspe sandstone fauna is believed to represent the Onondaga (Schoharie).

Grand Tower limestone.—Savage (1910) listed the Grand Tower fauna and reports *Paraspirifer acuminatus* and *"Spirifer" gregarius* in the upper part. In the Little Saline Valley the Grand Tower contains a coral bed in the lower part, and the upper layers are crowded with *Schizophoria.* These upper beds may belong to the Marcellus rather than the Onondaga. Beds containing *Spirifer lucasensis* occurring far below *Microcyclus* at the Bakeoven have been assigned to the Marcellus.

Gravel Point limestone (Cooper and Warthin).—At the base of the formation a foot of calcareous shale contains fossils like those in a blue shale 40 feet below the top of the Alpena limestone. At the top of the Gravel Point another blue shale, "the upper blue shale," or zone 6 of Pohl, contains crinoids and brachiopods similar to those of the Dock Street clay at the top of the Alpena. Therefore the interval occupied by the Gravel Point is essentially that of the upper 40 feet of the Alpena limestone. The *Chonetes emmetensis,* so abundant in the lower part of the Gravel Point limestone, also occurs at the base of the upper 40 feet of the Alpena.

Griffon Cove River beds.—Located between Fox River and the Forillon, Gaspe Peninsula, consist of red shale and gray limestone. The crinoid *Scyphocrinus* [*Camarocrinus*] is reported near the top of the lower quarter of the formation, and a small fauna of brachiopods is reported a little higher in the section. Kindle (1938, p. 20) lists *Spirifer vanuxemi* var., *Rhynchospirina,* and *Whitfieldella* and correlates the beds with the Keyser limestone of Maryland which is here regarded as Silurian. This sequence may also be related to the Clam Bank series of Schuchert and Dunbar.

Guilmette formation.—*Stringocephalus* occurs about 100 feet above the base, and *Platyschisma mccoyi* was found near the top. The lower part is therefore correlated with the *Stringocephalus* zone, and the upper part with the *Spirifer argentarius* zone of the Devils Gate formation which contains *Platyschisma.*

Harrogate limestone.—Proposed by Shepard (1926, p. 626) for Devonian beds exposed not far northeast of Harrogate in the Brisco-Dogtooth area of the Kootenay District, British Columbia. Since the naming of the formation Evans (1933, p. 142-145) discovered additional exposures in the same area. Fossils collected are listed by Kindle in Evans' report. A collection in the U. S. National Museum made by Dr. Edwin Kirk from the section east of Harrogate contains *Schizophoria "macfarlani," "Martinia" meristoides,* large *Productella, Atrypa,* and the coral *Mcgeea.* These fossils, particularly the first and last, suggest an Upper Devonian age (Chemung). Kindle on the other hand regards the same assemblage as Middle Devonian and relates it to the fauna of the Pine Point formation occurring under *Stringocephalus* in the Great Slave Lake area.

Heppel formation.—At least 3500 feet of sandstone and shale correlated with the Gaspe sandstone. Overlies the Causapscal formation (Alcock, 1935, p. 83-85).

Hungry Hollow formation (Warthin and Cooper, 1941).—New name used for the "Encrinal" and coral bed of the Widder in the southern peninsula of Ontario. Contains most of the Centerfield fauna.

Huron shale.—This name has been loosely used for black shales exposed in northern Ohio, Ontario, and part of Michigan. It has been regarded as "Portage" by some geologists and younger by others, depending on the interpretation of its relationship to the beds overlying it and to the Chagrin shale. According to Ulrich (1912, p. 165-166) the Huron shale is Mississippian and unconformably overlies the Chagrin shale to the east. In the same direction the Huron is overlapped by the Olmstead and Cleveland shales.

Prosser interprets the Huron shale as a facies of the Chagrin representing the passage of the Chagrin from a gray shale having a "Portage" facies to a black shale west of Cleveland. The writer agrees with this view. The Chagrin has been shown to be the sandy shale facies of the Conewango. It would be expected therefore that, as one traced the Chagrin westward, it would pass laterally into a black shale as most of the other Devonian members do.

A Mississippian age for the Huron shale seems to the writer most unlikely as it is overlain by the Cleveland and the Bedford shale. It is shown elsewhere (*see* Bedford shale) that Girty has dated the fauna of the Bedford shale as Devonian, and that it seems to correlate with the fauna of the Hamburg-Glen Park of the Kinderhook. Without arguing the Devonian or Mississippian age of this fauna, the writer has selected it as the upper limit of the Devonian.

Hypothyridina.—Because the various members of this genus have been widely and often incorrectly used to identify the base of the Upper Devonian, a discussion of this interesting rhynchonellid is important. Its rotund form and square front make the genus easy to recognize, but the identification of species is difficult. The known species are variable, a fact that has led to unfortunate assignments of specimens from widely separated parts of the Devonian column generally to *H. cuboides*. Stratigraphers have also fallen into the habit of regarding most occurrences of *Hypothyridina* as early Upper Devonian. Examination of the age of this genus in North America and Europe shows that this practice is not justified. This note is written in the hope that *Hypothyridina* will be used more cautiously as a guide fossil in the future.

In Europe *Hypothyridina* ranges from the Eifelian (Schulz, 1883) (Nohnerkalk with *H. procuboides*) through the *Stringocephalus* zone or Givetian *(H. procuboides, H. demissa)* (Torley, 1934) into and through the middle Frasnian (*H. cuboides* and varieties) (Maillieux, 1940)—*i.e.*, in Europe the genus ranges from early Middle Devonian through the middle of the Upper Devonian.

In the United States and Canada *Hypothyridina* is known at several levels and is represented by several species. A possible new species of doubtful affinities occurs in the lower Nevada limestone. *Hypothyridina venustula* is abundant in the Tully of New York; it occurs in the same formation in Pennsylvania and is regarded here as Middle Devonian. *H. intermedia* occurs in the Solon member of the Cedar Valley formation of Iowa which is correlated with the Tully. The *H. magister* is characteristic of the Shellrock which is placed on the chart as a calcareous facies of the Naples group. In the Devils Gate limestone of Nevada two species of *Hypothyridina* are known which belong in the Finger Lakes to Chemung stages. The higher one, *H. emmonsi*, occurs in the *Pachyphyllum* zone.

In the Great Slave Lake and Carcajou Mountain regions of northwestern Canada *Hypothyridina* occurs with *Cyrtospirifer disjunctus* at a horizon far above the Naples in the Chemung stage. A species of *Hypothyridina* identified by Stainbrook (1935, p. 254) as *H. emmonsi* occurs in the Independence shale of Iowa in association with a fauna like that of the Canadian occurrences. Thus in America the range of *Hypothyridina* is from high in the Lower Devonian to the middle of the Upper Devonian.

Independence shale (Merrill A. Stainbrook).—The Independence shale lies immediately below the Cedar Valley limestone and above the Davenport member of the Wapsipinicon. In a number of places shale, bear-

ing Independence fossils, may be seen in vertical section below the Cedar Valley and in at least two places above Davenport limestone. In a number of wells, 10 to 20 feet of shale occurs, as shown by the samples, below the Cedar Valley and above the Davenport, and in three of them Independence fossils were recovered from the shale. The discovery pit at Independence penetrated 20 feet of limestone and entered shale at the base of the Cedar Valley. At Fairfax, Iowa, a pit sunk through the basal 5 feet of the Cedar Valley shows several feet of fossiliferous shale immediately below. At no place does the Independence shale occur on Cedar Valley unconformably, and occurrences of the shale abutting Cedar Valley limestone are explainable as due to faulting. The fauna is [of late Devonian age] not the same as that of the Lime Creek [Hackberry] as there are many Independence species not found in that formation and vice versa. Species apparently similar are in some cases specifically or varietally different.

Independence shale (Cooper and Warthin).—The position and age of the Independence shale have long been subjects of debate, one group holding that it normally underlies the Cedar Valley and the other contending that the shale is not in its true stratigraphic position (Fig. 1). The formation was first discovered by Calvin (1878, p. 725) in a shaft sunk below the Cedar Valley at Independence, Iowa. Stainbrook (1935, p. 254) maintains that the shale underlies the Cedar Valley conformably but overlies the Davenport limestone of the Wapsipinicon unconformably and cites as supporting evidence the sinking of an artesian well at Shellsburg which showed Independence shale carrying typical fossils below 65 feet of Cedar Valley limestone.

Despite these contentions purporting to show the Independence below the Cedar Valley, the few known surface exposures and the fauna indicate to the writers that the shale is not in its normal position. In most occurrences shown to the writers by Stainbrook the exposed shale was supported on at least two sides by Cedar Valley limestone. The base of the shale was inferred to rest on Davenport limestone. These exposures suggested sinks filled by shale, and some were so interpreted by Savage (1920, p. 170, 180). The occurrence at Shellsburg, and others like it, are here believed to indicate that the well shafts penetrated caverns and channels long since filled by Independence shale. A similar occurrence of cavern filling is known from Chicago where late Devonian black shale occurs in caverns and crevices in Silurian dolomite (Weller, 1899, p. 483-488). Although the position of the Independence shale is equivocal, its anomalous position is best shown by its fauna.

The fossils of the Independence shale are totally different from those of the Cedar Valley. Whereas the latter contains no unequivocal Upper Devonian species or genera, the Independence contains forms not usually seen below the Upper Devonian in the United States, and not one Independence species is known in the Cedar Valley. The important Independence genera are: *Manticoceras, Ponticeras, Pugnoides, Cyrtospirifer* (related to *C. disjunctus*), *Ambothyris, "Dalmanella" infera* (related to *"D." danbyi), Sulcatostrophia, Douvillinella, Strophonelloides,* and *"Camerophoria" ambigua.* The goniatites (Miller, 1938, p. 71) clearly place this assemblage in the Frasnian of Europe or high in the *Manticoceras* zone of the United States. The presence of *C. disjunctus* and the *"Dalmanella"* place the fauna in the Chemung, the horizon in which the widespread spiriferoid first appears. Similarities are also evident with the Sly Gap shale of eastern New Mexico (San Andres and Sacramento Mountains), the Boule limestone of Alberta, the Carcajou Mountain beds, and Hay River limestone of northwestern Canada. Correlation with the Nunda (High Point) sandstone of New York is also indicated (J. M. Clarke, 1885, p. 72-76). Besides the forms mentioned Stainbrook (1935, p. 254) has identified *Hypothyridina emmonsi* which occurs high in the Devils Gate limestone of Nevada. The Independence fauna is the one assemblage in North America most closely related to the *"Cuboides"* zone of Europe as seen in the Frasnian (F_2) of Belgium.

In summary the writers hold that the Independence shale is not in normal position because: (1) It fills sinks and caverns; (2) its occurrence is spotty, there being no definite outcrop belt; (3) its fauna is that of the Nunda or High Point (Chemung) sandstone and the Frasnian (F_2) of Belgium.

Ipperwash limestone (Cooper and Warthin).—Uppermost formation of the Hamilton exposed along the shore of Lake Huron from Ipperwash Beach to Silica Point and in the vicinity of Ravenswood. Underlies the Kettle Point (Upper Devonian) shale, but correlation with the New York Hamilton is difficult. The Ipperwash contains many fossils, among them *Rhipidomella penelope, Spirifer granulosus, Stropheodonta concava, Tropidoleptus carinatus,* and *Cornellites* [*Pterinea*] *flabellus.* This assemblage indicates a Ludlowville age. Comparison with the Lake Erie sequence shows that the fossils named occur together at two levels only: the basal Wanakah (*Pleurodictyum* zone) and the Tichenor. The writers believe that the Ipperwash fauna is closer to that of the basal Wanakah than to the fauna of the Tichenor. *Pleurodictyum* has not yet been taken from the Ipperwash, but the large *Spirifer granulosus* is most suggestive of the Wanakah. Important Tichenor types such as *Vitulina*

and *Centronella* which are abundant on the Lake Erie shore are unknown in the Ipperwash. The evidence stated is neither extensive nor conclusive, and the correlation suggested must be regarded as tentative.

Ironside dolomite.—The fauna is sparse and consists chiefly of corals. In this member in a part of California adjacent to the Goodsprings area north of Sandy Wells road (U. S. Geol. Survey loc. 1994) is a small *"Spirifer"* suggestive of *S. argentarius*. This zone is therefore assigned to the portion of the Devils Gate limestone containing this fossil.

Ithaca formation.—According to Chadwick (1935, p. 858) the Ithaca formation represents the sandy facies of the Middlesex and Cashaqua shales of western New York. Caster (1933, p. 201) in abstract form revised the Ithaca sequence and suggests correlations that vary considerably from Chadwick's views. The following divisions of the Ithaca in descending order are proposed by Caster:

Ithaca formation
- Triphammer shale member 140 feet ..... (4)
- Marathon sandstone member 35 feet ..... (5)
- Williams Brook member 15-25 feet ..... (6)
- Cascadilla shale member 150 feet ..... (7)
- Six Mile shale member 80-100 feet ..... (8)
- Renwick black shale member 8-20 feet ..... (9)

According to Caster the Triphammer and Marathon members become the Oneonta to the east, and the Six mile shale to the west is equivalent to the Rhinestreet shale overlying the Cashaqua. Thus Caster correlates the Ithaca with a higher formation than does Chadwick. At present it is impossible to settle these important differences; only field work will settle the matter. (*See* Enfield also.)

Jefferson limestone.—Sections in western Montana about Threeforks and in the Phillipsburg Quadrangle show 640-800 feet of gray to black limestone. In the lower 100 feet at Logan, Edwin Kirk (U. S. Geol. Survey loc. 754) collected *"Spirifer" argentarius* and *Tenticospirifer utahensis*. At another locality (no. 673) 2¼ miles northwest of Princeton Kindle (1908, p. 8-10) collected the same two spiriferoids but also *Gypidula* and *Cyrtospirifer* suggestive of *C. whitneyi*. Unfortunately the position of the last two in the section is not known. The listed species are elsewhere known in the lower part of the Devils Gate limestone.

Deiss (1933, p. 41-43) revised the stratigraphy of the Jefferson formation in the Flathead and Lewis and Clark National Forests, separating about 1500 feet of rock into five members in ascending order: White Ridge limestone, Glenn Creek shale, Coopers Lake limestone, Lone Butte limestone, and Spotted Bear limestone. The writer studied fossils collected

by Deiss from these limestones and found that the Coopers Lake contained a useful fauna consisting of a few species: *Pachyphyllum, Atrypa* cf. *A. hystrix, "Spirifer"* cf. *S. mesacostalis, Stropheodonta,* and *Schizophoria,* which indicate a Chemung age.

In south-central Idaho, Ross (1934, p. 960) reports the Jefferson in the Bayhorse Quadrangle as 1150 feet of dark dolomite containing abundant corals. In the Borah Peak area, Idaho, the Jefferson contains *Pachyphyllum* among other corals.

In western Wyoming the Jefferson generally consists of buff limestone containing *Atrypa* aff. *A. missouriensis*[1] as its commonest species. In Yellowstone Park Girty (1899) reports a few Jefferson species, among them *Pachyphyllum* and *"Spirifer engelmanni"* which is very close to *Tenticospirifer utahensis.*

The evidence presented suggests that in southwestern Montana and the Yellowstone region the Jefferson should be correlated certainly with the *Spirifer argentarius* zone of the Devils Gate limestone. The presence of *Pachyphyllum* and *Cyrtospirifer* in the same areas indicates that the section probably extends to the *Pachyphyllum* zone of the Devils Gate. In northeastern Utah in Green Canyon, Kindle (1908, p. 16, 17) reports *Spirifer argentarius* and *Cyrtospirifer* from the Jefferson indicating the same range as in Montana and western Wyoming. To the northwest in the Flathead and Lewis and Clark National Forest areas the fauna of the Coopers Lake member suggests a Chemung age.

Kanouse shale.—According to Willard (1937, p. 272) the contained fossils are those of the Esopus (Schoharie?) rather than the Onondaga.

Kennett formation.—The presence of *Calceola* in this formation is not unequivocal evidence of Lower Middle Devonian age, as this coral is known from the Silurian elsewhere in the West. Furthermore, fossils from Gazel, California, collected by C. W. Merriam from this formation and now in the National Museum include *Conchidium* and *Encrinurus* in an assemblage that otherwise suggests Devonian.

Kettle Point black shale.—As pointed out by Kindle and Miller (1939, p. 154) this name has long been overlooked. It was proposed by Logan (1863, p. 387) for the black shales at Kettle Point, Lake Huron, Ontario.

Killians limestone.—*See* Genshaw.

Lake Church formation.—As listed by Cleland (1911, p. 12-20) the Lake Church fauna includes a few important species as follows: a costel-

[1] This species is not *A. missouriensis* Miller. For a description of true *A. missouriensis, see* Greger (1936).

late *Atrypa* (Pl. 13, fig. 12) known elsewhere in the Manitoba and Rogers City limestones, *Gypidula "comis"* like those of the Rogers City, *Spirifer* sp. (p. 82, Pl. 14, figs. 13, 14) related to *"S." grieri* and *"S." divaricatus* from the Dundee limestone, and *Trochonema* occurring also in the Rogers City limestone. It is not yet possible to place the Lake Church accurately in the Devonian column, but the fauna as listed suggests correlation with the Dundee and Rogers City limestones of Presque Isle County, Michigan. According to Raasch (1935, p. 261-262) the Belgium or basal member of the Lake Church is duplicated in fauna and lithology by the basal Devonian at Spring Valley, Minnesota. The writer has indicated a correlation of the Lake Church with the *Stringocephalus* zone (Rogers City limestone), and it is therefore interesting to note that Schuchert (1897, p. 417; Stauffer, 1922, p. 408) reported the discovery of loose *Stringocephalus* in Minnesota from a borrowpit just under the Lake Church equivalent.

Lingle limestone.—The middle part of the formation at its type locality contains *Tropidoleptus carinatus, "Spirifer" sculptilis, Vitulina pustulosa,* and *Centronella impressa* which link the formation to the Beechwood of Indiana and Kentucky. Use of the name Lingle for rocks overlying the Grand Tower limestone at Grand Tower is incorrect; these rocks are pre-Lingle (*Vitulina* Zone) and are referred to the St. Laurent formation. (*See* St. Laurent.)

Little Rock Creek limestone (Cooper, 1941).—Occurs just above the Logansport limestone on Little Rock Creek about a mile above Lockport, Indiana, and consists of about 7 feet of brittle, gray limestone containing *"Chonetes manitobensis", "Martinia subumbona", Leptostrophia,* and a few other fossils, all Hamilton types. These fossils may range in age from the Delaware to the Tully. Lithologically the rock is suggestive of the Tully, and this limestone is tentatively correlated with that formation.

Logansport limestone (Cooper and Warthin, 1941).—"Reef" or shelf facies limestone exposed along the Wabash River and its tributaries in the vicinity of Peru and Logansport, Indiana. Contains the same fauna as the Four Mile Dam limestone of Alpena County, Michigan, and the Beechwood of Indiana and Kentucky.

Long Rapids shale.—Black shale containing the brachiopod *"Pugnax pugnus"* and the spores of *Sporangites* (Kindle, 1924, p. 35) exposed in the Moose River region, Ontario. The formation is assigned to the Naples on the basis of the brachiopod.

Mackinac limestone.—Contains the lower Onondaga (Schoharie?) fauna with *Amphigenia elongata.*

Manitoba limestone.—Grayish-brown friable limestone about 80 feet thick at Point Wilkins, 4 miles north of Steeprock River, western Manitoba; overlies the Winnepegosis limestone containing *Stringocephalus.* The fossils listed include the gastropods *Büchelia tyrrelli* and *Omphalocirrus manitobensis* (Kindle, 1914, p. 254-257). The former also occurs in the Elm Point limestone below the Winnepegosis formation, and both species occur together in the Rogers City limestone of Presque Isle County, Michigan. The Manitoba limestone has generally been correlated with the late Devonion *Hypothyridina* zone, but that diagnostic genus has never been found in it. None of the species listed by Kindle from the Manitoba limestone is a late Devonian fossil, and the majority of the genera are those of the Middle Devonian. Therefore, because of the presence of *Büchelia* and the Middle Devonian aspect of the fauna the writer places the Manitoba limestone in the *Stringocephalus* zone, making the Elm Point, Winnepegosis, and Manitoba limestones a unit.

Martin limestone.—Long recognized as a correlate of the Hackberry of Iowa because of abundance of *"Spirifer" hungerfordi, "Spirifer" orestes, Strophonelloides reversus, "Spirifer" cyrtiniformis,* and *Pachyphyllum woodmani.* The presence also of *"Spirifer" mesacostalis* links the formation to the Chemung of the Appalachians and New York.

Milligen formation (Kirk and Cooper).—In the Borah Peak Quadrangle, south-central Idaho, the lower part of the Milligen is shaly and contains species of the Threeforks formation. In a ravine southwest of Freighter Spring, on the east side of Double Spring Canyon (U. S. Geol. Survey loc. 2745) Cooper identified the following species: *Cyrtospirifer monticola* (Haynes), *Camarotoechia* cf. *C. nordeggi* Kindle, globular *Athyris, and Cleiothyridina devonica* Raymond. Other Idaho localities have yielded similar species.

Mineola limestone.—Has yielded a fairly large fauna of generalized and long-ranging Middle Devonian types: *Megistocrinus, Cranaena, Pentamerella* (reported as *Gypidula*), *Pholidostrophia,* and *Conocardium.* The original assignment of the formation to the Onondaga (Branson, 1924, p. 15-24) was based on identification of such species as: *Pentamerella arata, Eunella lincklaeni, Athyris vittata, Schizophoria propinqua,* and the blastoid *Nucleocrinus verneuili,* the absence of dominant Hamilton species, and unconformable relations to the Callaway which was identified as Hamilton. The few Onondaga species listed from the Mineola are, without doubt, incorrectly identified. Of these erroneously identified forms the Mineola *Pentamerella arata* is totally unlike that species, as a comparison with Figures 17-23 on Plate 17 will show. The *Nucleocrinus* according to Branson "are never well preserved. None of them retains

the surface markings, and identifications must be made largely on the basis of shape". This genus occurs throughout the Middle Devonian, and species are known from the Hamilton that are difficult to separate from Onondaga forms. Consequently a correlation based on such an identification is insecure.

On the chart the Callaway has been assigned to the Tully, and the Mineola is also assigned there not on the basis of specific identities but because of the Cedar Valley affinities of the fauna. It is important in connection with the Mineola to mention that some outcrops assigned to this formation near Rensselaer in Ralls County are undoubtedly a continuation of the Cedar Valley (Upper Rapid) of Iowa and indicate a close relationship to the Callaway.

Minnewanka limestone.—Forms the bulk of the Devonian of the Rocky Mountains of Alberta. In general contains two faunas: the lower one typified by *"Spirifer" jasperensis* and the upper one by *"Spirifer whitneyi"*. The lower fauna is correlated by Warren (*see* chart) with the Jefferson limestone, while the *"whitneyi"* fauna is placed in the Chemung.

Montebello sandstone.—Great local development of sandstone in the Mahantango of Pennsylvania in Perry, Dauphin, and Northumberland counties. Ranges in age from Skaneateles through Ludlowville and possibly into the Moscow. At some localities contains the brachiopod *Rensselandia* in abundance.

Moose River sandstone.—Hitherto correlated with the Oriskany, but certain fossils occurring in it indicate that the age should be extended to the lower Onondaga (Esopus and Schoharie). The presence of *Spirifer arenosus* is sure indication of Oriskany age, while the occurrence of *Amphigenia* (Clarke, 1907, p. 247) indicates the Onesquethaw stage.

Mottville member.—A well-defined sandstone and shell breccia traceable from Cayuga Lake to Susquehanna Valley, New York. From the latter place eastward to Schoharie Valley the Mottville is marked by an abundance of the crinoid *Ctenocrinus*. At Cooperstown and Richmondville, New York, *Paraspirifer* occurs at the Mottville horizon. West of Cayuga Lake the Mottville is believed to be continuous with the Stafford limestone previously placed at the base of the Skaneateles. Because of the presence of *Paraspirifer* in the Mottville and its abundance below the Mottville in eastern New York, it seems best to transfer the Mottville-Stafford to the Marcellus.

Mount Marion sandstone.—*See* Silica shale.

Mowitza shale.—Contains a small fauna having as its most conspicuous element wide-hinged *Cyrtospirifer disjunctus* unlike any other member

of the genus yet reported from the West but suggesting types from the New York Chemung.

Muddy Peak limestone.—About 300 feet below recognized Mississippian rocks occurs a fossiliferous zone about 50 feet thick containing corals, *Atrypa,* the snail *Platyschisma mccoyi,* and the brachiopod *Tenticospirifer utahensis.* These fossils indicate equivalence to the *"Spirifer" argentarius* zone of the Devils Gate limestone. In the Goodsprings area not far west of the Muddy Mountains the same fossils appear in the Ironside and Valentine members of the Sultan formation. Thus the Muddy Peak is equivalent to the Ironside and at least part of the Valentine.

Nevada limestone.—As restricted by Merriam (1940, p. 14) contains three distinct faunas in two different types of lithology. The lower or shaly-weathering limestone contains Oriskany and Onondaga types. In the lower part of this division large *Meristella, Gypidula (coeymanensis* type), *Acrospirifer (murchisoni* type), and a large *"Spirifer"* suggestive of *S. arenosus* indicate the Oriskany affinities.

Above the Oriskany part of the shaly lower Nevada is a fauna containing *Leptocoelia, Acrospirifer, Chonetes macrostriata,* large *Dalmanites,* and large *Gypidula,* but most significant is the presence of a large *Calymene* related to *C. platys* of the Schoharie sandstone and lower Onondaga of New York. This species suggests an upper limit for the shaly Nevada which is not higher than lower Onondaga (Schoharie).

The upper part of the Nevada is more massive and often dolomitic; this portion contains two faunas, one suggestive of the Delaware and the other containing *Stringocephalus.* In the lower part (Marcellus equivalent) of the upper Nevada, *Leiorhynchus* and *Styliolina* occur with *Martinia*-like brachiopods strongly suggestive of *"M." maia* (Billings). Small *Pentamerella* collected in this zone on Lone Mountain by Cooper and Bridge suggest a species occurring in the Cherry Valley limestone.

In the dolomitic part of the upper Nevada limestone *Stringocephalus* is abundant in places and is assigned to a position correlative with the fauna of the Winnepegosis limestone. As no recognizable species occur with *Stringocephalus* in the Nevada limestone no alternative is possible.

In the Muddy Mountain area of southern Nevada Longwell found the *Chonetes macrostriata* fauna and *Stringocephalus,* indicating that the Nevada limestone is well represented in that area.

New Albany shale.—It is generally agreed that the lower part of this formation correlates with the Geneseo shale or Tully limestone of New York as it contains *Schizobolus, Styliolina,* and *Leiorhynchus quadri-*

costatum. This part of the New Albany is therefore placed in the Taghanic stage at the top of the Middle Devonian.

Above the Geneseo portion occurs about 80 feet of dark shales terminating in a green shale and zone of small concretions containing a marine invertebrate fauna. Above this zone occurs about 5 feet of dark fissile shale; then a disconformity is followed by a foot of shale that is succeeded by the Rockford limestone. The 5 feet of shale contains conodonts of definite Mississippian affinities (Huddle, 1934, Fig. 2). The marine fauna (Huddle, 1933) consists of 10 species that can be correlated with the Bedford shale and Hamburg oölite faunas. The presence of this fauna of latest Upper Devonian or earliest Mississippian age makes it clear that the bulk of the New Albany is to be assigned to the Devonian, as Huddle has already concluded, rather than to the Mississippian.

New Scotland.—In the vicinity of Evans Ferry, Tennessee, Miss Elizabeth Didcoct of Mount Holyoke College collected fossils of New Scotland age, a discovery new for eastern Tennessee.

Newton Creek limestone.—*See* Alpena limestone.

Nunda sandstone (High Point sandstone).—Usually correlated with the Hackberry of Iowa, but the presence of *"Dalmanella" infera, Douvillinella,* and a few other fossils indicates correlation with the Independence rather than the Hackberry as noted by Clarke (1885, p. 72-76).

Olentangy shale.—Dr. John Wells (oral communication) of The Ohio State University reports the presence of the Tully coral *Lopholasma* at the base of this shale indicating at least a partial representation of the Tully.

Onondaga limestone.—In western New York two faunas can be recognized: The lower one having many Schoharie and Camden elements and characterized by *Amphigenia* and many corals is best developed west of New York on the southern peninsula of Ontario. The Schoharie elements include *Centronella, Strophonella ampla, Cyrtinaella biplicata, Calymene platys,* and *Terataspis.* Camden elements are *Eodevonaria* and *Anoplia.* Overlying the *Amphigenia* fauna is one characterized by *Paraspirifer acuminatus* occurring at the top of the Onondaga in New York. It also characterizes the top of the Columbus and Jeffersonville limestones to the southwest but has not yet been found in the Ontario peninsula. So far as known its northernmost range is Pelée Island in Lake Erie and Wayne County, Michigan.

In central New York a third division of the Onondaga, the Seneca limestone, is a dark shaly rock underlying the Marcellus and containing

an abundance of *Chonetes lineatus, Dalmanites selenurus,* and large coiled cephalopods. This name had long fallen into disuse, but as the interval it defines is a well-marked unit it is here revived.

Orcas group.—Part of this group is dated as Devonian by an identification of *Atrypa reticularis* reported by Schuchert. These seem to be Middle or Upper Devonian types rather than Silurian forms (McLellan, 1924, p. 217-222).

Paraspirifer.—In Germany *Paraspirifer cultrijugatus* marks the top of the Lower Devonian and the base of the Middle Devonian, but in Belgium the *Paraspirifer* zone is regarded as the base of the Middle Devonian.

In the United States *Paraspirifer* is abundant at the top of the Onondaga, Columbus, and Jeffersonville limestones and is reported from the base of the Onondaga in Ontario. In New York the genus ranges out of the Onondaga for more than 1000 feet into the Mottville member at the top of the Marcellus. It is also a prominent member of the Silica shale fauna. *Paraspirifer* thus characterizes the Marcellus fauna as well as that of the Onondaga. In comparison with the European sequence on the basis of the range of *Paraspirifer,* the Onondaga appears to correlate with the Upper Coblenzian rather than with the Eifelian as hitherto claimed. The Marcellus then would correlate with the Eifelian or upper *Paraspirifer* zone. In this connection it is interesting to note that the *Stringocephalus* limestone (Rogers City) rests on the Marcellus (Dundee) limestone rather than the Onondaga.

Pegram limestone.—Recently this formation was examined in detail by Peoples (1931, p. 431-439) who suggests that the name Pegram be dropped in favor of Jeffersonville for the Onondaga part and Sellersburg for the Hamilton portion. Peoples gives a long list of fossils from the Pegram of the Harpeth River Valley, west of Nashville, Tennessee, which shows the presence of many Hamilton species but few of Onondaga affinities. Of the latter *Nucleocrinus verneuili* is often misidentified, and blastoids of this type are now well known in the Hamilton. The writer examined the specimens of *"Spirifer" gregarius* reported by Peoples and found one of them to be an *Elytha* and the other a spiriferoid of unknown affinities. Doubt is therefore cast on the unequivocal Onondaga species reported.

After examination of the Pegram exposures on Mill Creek in the Waynesboro Quadrangle and the exposures on U. S. highway 70 in the Harpeth Valley the writer concluded that the part of the Pegram containing *Tropidoleptus* and *Hadrophyllum* is definitely of Hamilton age but that the lower part may be Hamilton or Onondaga; at all exposures seen no fossils of unequivocal Onondaga age were collected.

Besides the areas of Pegram mentioned Dunbar (1919, p. 101) reports this limestone over calcareous Camden at the "Whirl" north of Bakerville, Tennessee. This section exposes the only known calcareous Camden, and over a covered interval of 18 inches occurs a light-gray limestone composed almost wholly of corals both simple and compound that is assigned to the Pegram. Inasmuch as the Camden contains corals and this area is some distance from the main area of Pegram outcrop it is suggested that the bed probably belongs to the Camden rather than to the Pegram.

Pendleton sandstone.—Study of a large collection of Pendleton fossils made by Dr. John M. Clarke reveals a relationship of the Pendleton fauna with fossils of the Amherstburg dolomite. The peculiar and little known spiriferoid *Prosserella subtransversa* occurring with specimens of *Panenka, Pentamerella* aff. *P. arata, Proetus crassimarginatus,* and abundance of a small *Atrypa* (Sherzer and Grabau, 1910, p. 162, Pl. 20, fig. 1) indicate the suggested correlation. The Amherstburg dolomite has been correlated with the Lower Onondaga which contains many Schoharie elements. Inasmuch as the Lucas and Amherstburg may be facies of one formation the Pendleton is shown on the chart as equivalent to both formations.

Percha shale.—Fauna is composed mostly of Upper Devonian types, but a few species such as *Athyris coloradoensis* suggest Mississippian types. The shale is dated by the similarity of *Syringospira prima* to *"Cyrtia" alta* of the Amity shale situated in the lower part of the Conewango stage.

The so-called Percha, Sly Gap shale (Stevenson, 1941, p. 163) of the San Andres and Sacramento Mountains of south-central New Mexico contains the Independence fauna and is older than the type Percha farther west in New Mexico near Silver City. It is interesting to note that the Sly Gap fauna includes *Spirifer orestes* along with more typical Independence species, and the presence in it of *Tropidoleptus carinatus* is a link to the Chemung of New York.

Petoskey formation (Cooper and Warthin).—Contains several faunas of different age. At the base is an assemblage suggestive of the Norway Point of Alpena County, Michigan. Above this is a fauna resembling that of the Potter Farm formation, exposed at the junction of U. S. highway 31 with Michigan State highway 131. This is followed by an assemblage containing an element of the Thunder Bay fauna, the blastoid *Heteroschisma gracilis* (Wachsmuth), and exposed on the Lake Michigan shore 1¼ miles north of Norwood.

Above the Thunder Bay equivalent occurs a fauna that must be assigned to the Upper Devonian (Sherburne). Here occur a few feet of thin-bedded limestone and soft shale (?) containing *Actinoptera, Schizophoria, Leptaena,* and large *Pentamerella.* On top of this zone an undetermined thickness of shale (not over 3 feet) contains nodose *Melocrinus, "Reticularia"* cf. *"R." laevis,* and *Pugnoides.* The presence of the last two places the upper fauna as of Sherburne (*"Reticularia laevis"*) age. The *"Reticularia"* bed is overlain by black shale and greenish-gray limestone containing *Styliolina* and *Buchiola* which are correlated with the Naples (Cashaqua).

Portland Point limestone.—Shell breccia and crinoidal limestone extending from Erie County to Potter Hollow, Albany County, New York. In Schoharie Valley the member is a quartz pebble band containing characteristic Portland Point fossils (such as *Centronella*). Along the Delaware River Cooper and Chadwick discovered the Portland Point with abundance of *Vitulina* and occasional *Centronella* in Elks Charles Brox Memorial Park and in a small glade ½ mile southeast of Sparrowbush near Port Jervis, New York. The member has not yet been seen in Pennsylvania but should occur there.

Potter Farm formation.—Contains species related to those of the Thunder Bay formation and elements of the Cedar Valley formation.

Ragland sandstone.—Contains *Tropidoleptus carinatus, "Spirifer" venustus, Leptaena,* and *Anoplotheca camilla* (reported as *A. acutiplicata*) associated with abundant corals and other common Hamilton types. The corals and *"S." venustus* suggest correlation with the Centerfield formation, but the presence of *A. camilla* and *Leptaena* suggest a greater age, possibly *Marcellus,* as both species are known that low in the Hamilton (Cleland, 1903, p. 20-21; Cooper, 1933, p. 549). The Ragland is therefore tentatively correlated with the *Meristella*-Coral zone of the Schoharie Valley sequence occurring about 250 feet above the Onondaga limestone and containing *"Spirifer" venustus.*

Rensselandia [*Newberria*] *zone.*—The brachiopod *Rensselandia* [*Newberria*] is a large, generally elongate, smooth-shelled brachiopod resembling *Amphigenia* or *Rensselaria.* In the United States five species are known: *R. claypolei* occurring in the Montebello sandstone of Pennsylvania and the Beauvais sandstone of Missouri; *R. johannis* Hall and *R. cordiforme* Stainbrook occurring in the *Profunda* zone of the Solon member of the Cedar Valley not far above *Hypothyridina intermedia; R. missouriensis* (Swallow) from a zone between the Cooper and Callaway now called the Ashland limestone; *R. laevis* (Meek) occurring with

Stringocephalus in the Mackenzie Valley, northwest Canada. A species not yet described is known from the Rogers City limestone of Presque Isle County, Michigan. In Germany the genus is known from the upper part of the Eifelian and from lower and upper Givetian; its range is thus the same as that of *Stringocephalus*. *Rensselandia* thus has particular significance in stratigraphy in indicating the *Stringocephalus* zone where that genus is absent.

In the United States and Canada *Rensselandia* is known with *Stringocephalus* in the Mackenzie Valley and occurs in the Rogers City with other *Stringocephalus* associates. In Iowa and Missouri it occurs in equivalents of the Tully, and in Pennsylvania it is known in a considerable thickness of middle Hamilton rocks. Consequently the Hamilton above the Marcellus plus the Tully are regarded as the equivalent of the Givetian.

Rogers City limestone.—Exposed in the great quarry of the Michigan Limestone and Chemical Company at Rogers City, Presque Isle County, Michigan. Consists of 70 feet of limestone overlying the Dundee limestone containing *"Spirifer" lucasensis*. The Rogers City contains a fauna including elements of the Elm Point, Winnepegosis, and Manitoba limestones such as *Büchelia tyrrelli* and *Omphalocirrus manitobensis* (Whiteaves). The brachiopod *Rensselandia* is also known and emphasizes the relationship to the *Stringocephalus* zone. Although *Stringocephalus* has not yet been found, the Rogers City molluscan fauna contains bizarre types known elsewhere on this continent only from the limestones of Manitoba (Ehlers and Radabaugh, 1938, p. 441-446).

St. Laurent limestone.—According to present knowledge this limestone occurs in two areas not yet satisfactorily correlated. One area is located in southwestern Illinois in Union and Jackson counties and an adjacent series of outcrops on the west side of the Mississippi in the Altenburg Quadrangle, Missouri. The other is in the Little Saline Valley south of Ste. Genevieve, Missouri.

Above the Grand Tower limestone in southern Jackson County occurs a zone about 10 feet thick containing the coral *Microcyclus discus*. Overlying this zone about 40 feet of limestone abound in *Tropidoleptus* and *Chonetes* cf. *C. coronatus*. The *Microcyclus* zone was seen in eastern Missouri at Union School about 0.8 mile south of Seventysix. Above this zone at the same locality occurs a considerable thickness of Hamilton rocks capped by a granular limestone abounding in corals and suggestive of the Lingle limestone (*Vitulina* zone).

In Little Saline Creek Valley and on St. Laurent Creek 100 to 275 feet of sandy limestone contains Hamilton fossils. No zones were recognized

as common to the two localities, and none of the zones of the more southern Jackson County area, such as the *Microcyclus* zone, were recognized in the Little Saline Valley area.

The writer regards the St. Laurent limestone as lower Hamilton (Cazenovia stage) and below the Lingle limestone (*Vitulina* zone). The *Microcyclus* beds are regarded as probably of Marcellus age, but to them it may be necessary to add a part of the upper Grand Tower containing a *Spirifer* suggestive of *S. lucasensis* of the Dundee. At Devils Bakeoven and in the St. Laurent of the Little Saline Valley occurs a large pelecypod of the genus *Gosselettia* (*G. triquetra*) suggestive of the Marcellus and Skaneateles. The present position of the St. Laurent is tentative, but it seems unlikely that the formation can be placed above the Lingle as no post-Centerfield (Tioughnioga) formations are now known in the Mid west.

Schoharie formation in New York (Goldring and Flower).—The Schoharie formation in the Schoharie Valley region is typically a mud-textured siliceous limestone, dark bluish-gray when fresh, weathering to a brown porous sandrock, with an estimated thickness of 5 to 6 feet which dwindles in its most western exposure at Cobleskill to 35 inches of a fine-grained, siliceous limestone, with chert, characterized by a poor fauna of corals, few brachiopods, gastropods, and trilobites instead of the typical rich cephalopod fauna, with brachiopods, gastropods, and pelecypods abundant. There is no sharp contact between the Schoharie and Onondaga. Eastward in the Helderbergs (Capital District), where the typical Schoharie is best exposed, the formation shows an upper 32-inch heavy bed of dark blue-gray, fine-grained siliceous rock, weathering into a spongy sandrock, the portion that characterizes the Schoharie valley. The lower 30 inches is thinner-bedded and, when fresh, resembles a dark-blue, fine-grained limestone and appears to be the portion of the Schoharie that thickens southward in the Hudson Valley where the Schoharie formation loses the typical lithology entirely and becomes a shaly limestone with chert in the upper portion. This facies of the Schoharie, with a radical change in the composition of the fauna to one consisting largely of small brachiopod genera with a representation of a few bryozoans, corals, gastropods, cephalopods, and trilobites, attains a maximum thickness of 80 to 90 feet (12 to 17 feet transitional) in the Kingston region, previously interpreted as upper fossiliferous Esopus. These beds steadily thicken southwestward with much the same lithology and fossil content until in the Port Jervis region (Orange County) a thickness of between 215 and 235 feet is reached in beds in "Trilobite mountain" previously identified as basal Onondaga.

Schoharie fauna.—The work of Goldring and Flower has clarified one of New York's puzzling faunas. The supposed upper Esopus fauna consisting of a few species including *Eodevonaria, Leptocoelia, Anoplotheca,* and *Chonostrophia* now proves to be a facies of the Schoharie. The genera named suggest the Camden chert of Tennessee and its correlates in Illinois and Ontario. The fauna of the Camden and its correlates has been difficult to place because of the numerous Oriskany elements. It now assumes its proper position when correlated with the Schoharie. The so-called Onondaga of the Southern Appalachians now proves to be Schoharie, a part of the Onondaga rather than the whole formation.

Seneca limestone.—See Onondaga.

Sheffield formation.—Laudon (1935, p. 246) reports *Athyris angelica, Productella lachrymosa,* and *Spirifer disjunctus* and suggests a correlation with the New York Chemung. In New York these fossils overlie the restricted Chemung, and in Iowa the Sheffield overlies the restricted Chemung equivalent, Hackberry shale. It thus seems clear that the Sheffield is of Cassadaga age and not Kinderhook as claimed by some.

Shell Rock limestone.—Fauna is of early Upper Devonian age containing: *Pachyphyllum, Hypothyridina, Tenticospirifer* [*Trigonotreta shellrockensis* Belanski], *Platyschisma.* This fauna had hitherto been thought to be confined to Iowa, but the writer's studies indicate that it is widespread in western United States, its elements occurring in the Jefferson, Muddy Peak, lower Devils Gate, lower Minnewanka, and parts of the Sultan and Silverhorn limestones. Belanski's *Trigonotreta shellrockensis* is close to *Tenticospirifer utahensis,* and his *Spirifer cardinalis* is similar to *"S." argentarius.*

Silica shale.—That the Silica shale is referable to the Hamilton is a certainty, but its precise position is uncertain. According to the writer's views the Silica section covers a fairly long time interval ranging from upper Marcellus to high Skaneateles. The Silica shale overlies the "Blue-bed" of Carman (*in* Bassett 1935, p. 437-439) which is probably of high Dundee age and is overlain by the Tenmile Creek limestone of Centerfield age. The Silica thus occupies an interval between Marcellus and basal Ludlowville.

The "Blue-bed" contains the pelecypod *Gosselettia,* a good index to the lower Hamilton. Above this basal bed 14 feet of shale abounds in *Paraspirifer bownockeri, Mucrospirifer prolificus,* and *Chonetes* cf. *C. coronatus.* As *Paraspirifer* is abundant in the Mount Marion of New York and is found in the Solsville and Mottville members the Silica is correlated with the upper Marcellus. Incidentally the fauna of the

Mount Marion occurring at the top of Great Falls west of Catskill is very close to that of the Silica shale.

In the Silica Quarry the *Paraspirifer* zone is terminated for convenience at the ***Rhipidomella*** zone. In the section along Tenmile Creek between the ***Rhipidomella*** bed and the Tenmile Creek limestone occurs 6 feet of shale that contains *Schizophoria, Camarotoechia,* and other fossils suggestive of the Ferron Point and perhaps the Genshaw of the Michigan sequence.

Silver Creek limestone.—Rests on the Speeds limestone of upper Marcellus age and underlies the Centerfield equivalent, the Beechwood limestone. Although the Silver Creek contains elements of the Solsville sandstone fauna, it seems best correlated with the Delphi Station shale. In common with the latter it contains *Roemerella, Macrochilina, Bembexia, Limoptera,* and *Paracyclas. Conularia* and *Ptychodesma* suggest a Solsville age.

Silverhorn dolomite.—Gray dolomite capped by a thick bed of quartzite exposed in the Bristol Quadrangle and in the vicinity of Pioche, Nevada. *Stringocephalus* was found loose at Dutch John Mountain (Westgate and Knopf, 1932, p. 16-19), 40 miles north of Pioche, and its source was undoubtedly beds low in the Silverhorn. At 2300 feet up in the section south of Silverhorn *Tenticospirifer utahensis* was found. At other sections *"Spirifer" argentarius* occurs. It is evident therefore that part of the Silverhorn is referable to the *Stringocephalus* zone (upper Nevada limestone) and part to the *S. argentarius-T. utahensis* zone (upper 700 or 800 feet) which is correlated with the lower Devils Gate and Jefferson limestone.

Skunnemunk conglomerate.—Consists of conglomerates alternating with red sandstones, the formation varying in thickness from 300 to 2500 feet. Has yielded no fossils, consequently in order to arrive at an age assignment the Green Pond and Skunnemunk Mountain sections may be compared with other known areas of the Devonian. According to the writer's views this great outlier is a continuation of the sequence west of Catskill and represents about the same facies as found in that area. From Albany and Catskill the Hamilton outcrop belt extends seaward rather than parallel to the old shore. This is shown by the fact that along the Catskill Front the marine facies of the Hamilton comes more and more to dominate the section, until the entire sequence is marine at Port Jervis. The shoreward continuation of the Catskill sequence the writer believes to be the Skunnemunk outlier and its continuation into New Jersey.

The stratigraphic sequence of the outlier and the thicknesses involved are:

	Feet
Skunnemunk conglomerate	300-2500
Bellvale sandstone	1000-1800
Cornwall shale	200-1000

Willard (1937, p. 271-272) assigned the Cornwall shale to the Onondaga. This would leave 1300-4300 feet of post-Onondaga sediments. Willard assigned the Bellvale to the Marcellus, and this seems correct when one considers that about 1300 feet of Marcellus is known in the vicinity of Catskill (Bakoven 180 feet, Mt. Marion 800 feet, and Ashokan 300 feet). This leaves the remaining 300 to 2500 feet equal to the remainder of the Hamilton which in Schoharie Valley is about 1800 feet thick and is much thicker on the Catskill Front although the limits are not exactly known (probably about 3000 feet). On this evidence the entire sequence, even allowing for part of the Cornwall to be Hamilton, is probably not younger than Hamilton. A possible Taghanic equivalent could be present, but the writer favors the view that the entire sequence is Hamilton and Onondaga only and has so represented it on the chart.

Sly Gap formation.—Named by Stevenson (1941) for dark shale and limestone outcropping in the Sierra Caballo, and San Andres and Sacramento mountains, south-central New Mexico. Contains the Independence fauna according to Stainbrook (1935b). Stevenson correlates the Sly Gap with the Martin limestone of Arizona. Possibly partial equivalence with the Canutillo formation is suggested above. (*See* Canutillo, Percha shale.)

Snyder Creek shale.—Its generic assemblage is predominantly Middle Devonian, but a few Upper Devonian types are present: *Gruenwaldtia gregeri, Productella callawayensis, Strophonelloides crassus,* and *Dactylocrinus concavus.* Along with these occurs a species of *Pentamerella,* a genus that is much more abundant in the Middle Devonian. Because of some Middle Devonian aspects of the fauna and because it is definitely post-Tully the writer has placed it in the Finger Lakes (Genesee group) or lowest division of the Upper Devonian; possibly it should be placed higher with the Ithaca fauna.

Speeds limestone.—Name applied to light-brown limestone containing *"Spirifer" mucronatus* in southern Indiana (Sutton and Sutton, 1937, p. 331). Includes the *Hadrophyllum* beds of the Delaware and underlies the Deputy limestone.

Squaw Bay formation (Warthin and Cooper).—Dolomite with thin layers of limestone aggregating 3-12 feet in thickness. Contains a thin

zone near the bottom nearly completely composed of shells of *Styliolina fissurella*. Other fossils are: *Paracardium, Buchiola, Diaphorostoma pugnus,* and the goniatite *Koenenites cooperi.* Correlated with the Genundewa of New York on the basis of abundance of *Styliolina,* the *D. pugnus,* and general assemblage. Regarded as lowest Upper Devonian of eastern United States because of presence of *Koenenites* which occurs in the lowest zone of Upper Devonian goniatites in Germany.

Starbird formation.—Named from Starbird Ridge, Windermere, Kootenay District, British Columbia. Consists of arenaceous and argillaceous limestone about 230 feet thick on the east end of the ridge. Kindle (*in* Walker, 1926, p. 35) reports *"Spirifer"* cf. *"S." argentarius, "S."* cf. *"S." raymondi,* and *Schizophoria* which suggest an Upper Devonian age and correlation with the Jefferson and lower Minnewanka limestones.

State Quarry limestone.—Occupies erosion pockets in the Cedar Valley in a limited area in east-central Iowa. Fauna includes abundance of *Pugnoides, Atrypa,* and *Athyris,* and a species of nodose *Melocrinus* (Stainbrook and Ladd, 1926). The last mentioned and the *Pugnoides* suggest a position low in the Upper Devonian, and the formation has therefore been placed at the top of the Genesee group. Possibly it should be placed higher in the Naples stage (Ithaca).

Stone Mill limestone.—A lens of crinoidal limestone containing the Centerfield fauna located on both sides of Chenango Valley south of Hamilton, New York. Contains a new species of *Prismatophyllum.* The Ludlowville shaly sandstone overlying the Stone Mill also contains the Centerfield fauna. The Stone Mill represents the last recognizable phase of the Centerfield where it passes into the undifferentiated sands east of Chenango Valley.

Stony Hollow sandstone.—A conspicuous layer of calcareous sandstone 75-100 feet thick exposed at Port Jervis, and from Kripplebush northeastward to the southwest corner of Albany County, New York. Known also near Echo Lake, Pennsylvania. Between Kripplebush and Catskill it forms a conspicuous line of cliffs and waterfalls. Northeast of Catskill this sandstone has been traced to the fall of Onesquethaw Creek and from there westward where it becomes the Cherry Valley limestone in Schoharie Valley. Fauna contains many new species, among them a new *Pentamerella* that also occurs in the Cherry Valley limestone and a species of the rare brachiopod *Kayserella.* Tracing of the Stony Hollow into the Cherry Valley has brought order to the sequence along the Catskill Front; it has proved that the Bakoven is

equivalent to the Union Springs member and that much of the Mount Marion belongs to the Chittenango member.

Stringocephalus zone.—Because it is large and easily identified and has a fairly restricted range, *Stringocephalus* is an important index fossil. In Germany where it is most abundant, its range is from the upper Eifelian through the Givetian, and in general practice its presence indicates the upper half of the Middle Devonian (Givetian). In the United States *Stringocephalus* occurs in southeastern and central Nevada, in western Utah, and southeastern Alaska. In Canada it has been reported from the Ramparts of the McKenzie River, Great Slave Lake, and Lake Winnepegosis, Manitoba (Kindle, 1921, p. 21-24; Kirk, 1927, p. 219-222). In Midwestern United States the genus has been reported from southern Minnesota (Stauffer, 1922, p. 408), but the discovery has not been authenticated. In Presque Isle County, Michigan, many species of the Manitoba *Stringocephalus* limestone have been taken from the Rogers City limestone, which lies between the Marcellus (Dundee) limestone and Traverse (Bell) shale.

The position of *Stringocephalus* between the Dundee and the Bell places the remainder of the Hamilton (Skaneateles to Moscow) and the Tully in a post-*Stringocephalus* position. But the faunas of these formations indicate a Middle rather than Upper Devonian age. Consequently it is believed that the Hamilton (above the Marcellus) and the Taghanic belong in the upper part of the *Stringocephalus* zone, corresponding to the upper *Stringocephalus* stage of Germany.

Although it is clear that the Rogers City limestone is low in the *Stringocephalus* zone it is more difficult to place the *Stringocephalus* beds of the West. In the Eureka district *Stringocephalus* overlies a Marcellus equivalent and is overlain by the *Stromatopora* zone, followed by the lower Devils Gate formation of lower Upper Devonian age. Perhaps the *Stringocephalus* zone of the West equals the Rogers City plus the Hamilton and the Tully, but no fossils accompanying *Stringocephalus* are known to prove this point.

Little help in this dilemma can be got from the fauna of the *Stringocephalus* zone at the Ramparts of the McKenzie River, a fauna that contains elements of the Nevada limestone (*Leiorhynchus castanea* Meek) and elements of the Winnepegosis limestone (*Rensselandia* and *Gypidula*). This evidence suggests that the American and Canadian occurrences represent a single zone. The writer knows no contradictory evidence and has therefore placed all the *Stringocephalus* occurrences as equivalent and low in the Givetian. The longer range of *Rensselandia* is taken to show

the upper Givetian or upper *Stringocephalus* age of the upper Hamilton, Cedar Valley, upper Traverse, and Tully.

Tenmile Creek limestone.—Overlies the upper Silica shale on Tenmile Creek, about a mile south of the Silica Quarry, southwest of Sylvania, Ohio. Contains the Centerfield species *Strombodes alpenensis* and *Cyclorhina nobilis* associated with many species of Centerfield type.

Threeforks shale.—Sequence and faunas well described by Haynes (1916, p. 13-30) who reports about 145 feet of shales and beds of limestone. Above this sequence occurs yellowish sandy limestone containing *Syringothyris*. In the Threeforks proper occur a variety of fossils including large *Cyrtospirifer, Productella,* and *Leiorhynchus* suggesting affinity with the Percha shale of New Mexico and the Ouray limestone of Colorado. The pelecypods and goniatites on the other hand indicate a somewhat older age. Of the former the most important is *Loxopteria* which in New York is restricted to the Canadaway group. The goniatites give another clue to the position of the Threeforks by making comparison with the German column possible. The most important Threeforks goniatites are: *Raymondiceras simplex* (Raymond), *Platyclymenia* (*Pleuroclymenia*) *americana* Raymond, and *P.* (*P.*) *polypleura* Raymond which, according to Schindewolf (1934), indicate correlation with the *Prolobites-Platyclymenia* stage (Oberdevon III). As this stage overlies the *Manticoceras* zone (Genesee to Canadaway groups), the Threeforks is placed in the succeeding Conneaut group of the Cassadaga stage. This position is corroborated by the occurrence in the Threeforks of brachiopods almost identical to *"Camarotoechia" duplicata,* chief index to the Conneaut.

The *Syringothyris* beds above the Threeforks and below the Mississippian (Madison) formation Schuchert (1910, p. 546) assigned to the Louisiana limestone. As *Syringothyris* is known in the Conewango stage (Chagrin) and as the Mississippian age of the Louisiana has been questioned, it is not unlikely that the Threeforks *Syringothyris* zone will ultimately be assigned definitely to the Devonian (Conewango). For the time being the beds are placed in the Devonian or Mississippian column.

In northeastern Utah a zone of dark shaly rock between the Jefferson and the Madison has been referred to the Threeforks. This zone contains large *Schizophoria,* large *Productella?, Syringothyris, Rhipidomella,* and a *Spirifer* suggesting *S. marionensis* of the Louisiana. This shale is also placed in the Devonian or Mississippian column as it is definitely not Threeforks shale.

Thunder Bay formation (Cooper and Warthin).—This name preoccupies Partridge Point formation of Warthin and Cooper (1935, p. 525). The fauna contains Cedar Valley as well as Hamilton elements such as: *Nucleocrinus obovatus* Barris, *Heteroschisma gracilis* (Wachsmuth), *Strobilocystites?*, and *Stereocrinus*. The brachiopods contain Cedar Valley and Hamilton types, but the pelecypods are mainly New York Hamilton forms. Another New York Hamilton link is the trilobite *Dipleura dekayi*. As this formation underlies the Squaw Bay limestone, a correlate of the Genundewa limestone, it could represent a calcareous facies of the Geneseo, but the writers prefer to correlate it with the Tully because of the close faunal tie with that formation and the Cedar Valley. Furthermore the beds assigned to the Thunder Bay on the shore of Lake Michigan contain a trilobite identified with *Scutellum tullium depressum* Cooper and Cloud (1938, p. 459) which occurs in the lower Cedar Valley of Calhoun County, Illinois.

Tully formation.—For many years the Tully had been placed as the top member of the Hamilton group, but in 1890 H. S. Williams (p. 481-500) presented evidence designed to show that this limestone is the homotaxial equivalent of the Upper Devonian *"Cuboides"* zone of Europe. Re-examination of the evidence and new information indicate that the Tully may, rather, be the homotaxial equivalent of the upper *Stringocephalus* zone (Wells, 1940) and that the true homotaxial equivalent of the European *"Cuboides"* zone is the Independence-Nunda (High Point) fauna high above the Tully.

In discussing the Tully fauna H. S. Williams neither considered nor understood the entire fauna. His collections, which are in the U. S. National Museum, were taken from the lower part of the Tully only (Tinkers Falls and Apulia members) at Tinkers Falls, Tully, Cuyler, and a few neighboring localities. The collection thus does not embrace all the Tully of the State nor does it include the fauna of the West Brook member of Cooper and J. S. Williams, which was well known to S. G. Williams (1887, p. 26-28). This latter fauna H. S. Williams (1890, p. 496, footnote) erroneously said was derived from Hamilton shales below the Tully. H. S. Williams further regarded the Tully fauna as consisting of about 50 species, but the formation is now known to contain more than 260 species most of them Hamilton forms or forms with Hamilton antecedents. It is therefore evident that H. S. Williams had no conception of the total Tully fauna.

According to H. S. Williams the more important Tully species are: *Schizophoria tulliensis, Schuchertella arctostriata, Leptostrophia tulliensis, Chonetes aurora, Atrypa reticularis, A. aspera, Hypothyridina*

venustula, Spirifer mucronatus tulliensis, Cyrtina hamiltonensis, Spirifer tullius, Ambocoelia umbonata, Productella tulliensis, Elytha fimbriata, Phacops rana, Greenops boothi, Scutellum tullium, Platyceras symmetricum. Eleven of these species—2, 5, 6, 9-15, and 17 of the list—can be dismissed from consideration in age determination because they are long-ranging Hamilton types. This leaves a few exotic forms for consideration. *Schizophoria tulliensis* now has little significance because the genus is well known in the lower Hamilton from which many Tully species were derived.[2] *Leptostrophia tulliensis* shows characters that link it with the *Nervostrophia* stock of the Ithaca rather than with Hamilton forms. *Chonetes aurora* may be related to Hamilton species as the genus is abundant there, and the species is identified from Manitoba. A nearly identical species occurs in the Solon of Iowa. *Hypothyridina venustula* is an exotic form, but its antecedents are known in the pre-Tully Eifelian and Givetian. *Spirifer mucronatus tulliensis* is related to *S. mucronatus* and may represent passage to the Ithaca *S. posterus* by greater development of the dental plates. *Scutellum tullium* has Middle Devonian antecedents in the Givetian of Europe and the Winnepegosis limestone of Manitoba. Aside from *Nervostrophia, Spirifer mucronatus tulliensis,* and a possible representative of the genus *Manticoceras* (Miller, 1938, p. 74-76), no unequivocal Upper Devonian types occur in the Tully. If the Tully actually were homotaxial with the *"Cuboides"* zone of Europe more than two or three exotic types would be expected. In this respect the Tully fauna cannot be compared with that of the Independence-Nunda in which many European types appear in a resident fauna.

That the Tully cannot be the homotaxial equivalent of the European *"Cuboides"* zone is shown by the fact that, besides *Hypothyridina* and *Scutellum,* no other elements of the *"Cuboides"* fauna are found in it. One of the important *"Cuboides"* types is *Cyrtospirifer verneuili,* but this genus in North America has not been seen below the Naples. Other important *"Cuboides"* genera are *Gypidula, Ambothyris,* and *Pugnoides,* but these have never been seen in the Tully. *Gypidula* occurs in the Cedar Valley, a Tully correlate, yet there it occurs with *Rensselandia* and belongs to the Middle Devonian. Thus few European elements appear in the Tully, but the Independence fauna or *"Cuboides"* equivalent contains many European types including *Cyrtospirifer.* It seems best now to regard the Tully as of Middle Devonian age, and to make a stage, the Taghanic stage, to include it and its correlates in the Midwest

[2] After disappearing before the Ludlowville and Moscow, *Bembexia sulcomarginata* and *Paracyclas lirata,* both Marcellus and Skaneateles types, reappear in the Tully.

and the overlying Geneseo shale which contains *Hypothyridina* in Kentucky.

Valentine limestone.—Contains *Platyschisma mccoyi* and a small spiriferoid similar to *Tenticospirifer utahensis* indicating correlation with the lower Devils Gate and the Jefferson limestone.

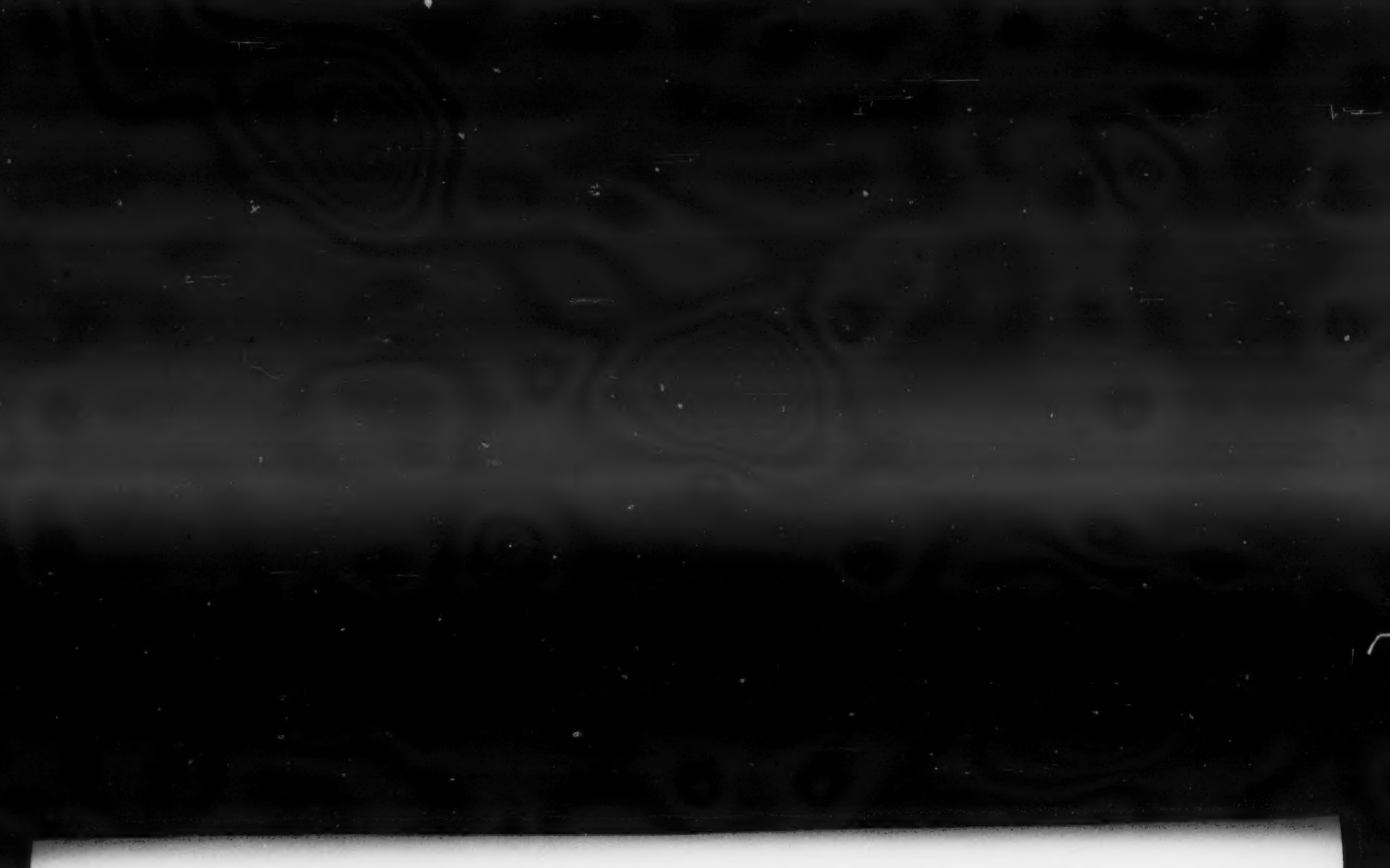
Wapsipinicon limestone.—Poorly fossiliferous sediments overlying the Niagaran and underlying Cedar Valley limestone. According to Stainbrook (1935a, p. 249-252) consists of the following members in ascending order: Coggon dolomite member, Otis limestone, Kenwood shale, Spring Grove limestone, and Davenport limestone. The Coggon contains a brachiopod suggesting *Emanuella subumbona* but specifically different, and a small *Conocardium*. The Otis contains *Emanuella*, but the rest of the members are without fossils. The Wapsipinicon is referred to the Taghanic stage because of the similarity with the Cooper limestone and Potter Farm formations. The Cooper contains a small *Emanuella*, and a small *Conocardium* is abundant in the Potter Farm. The latter also contains a snail suggestive of *Turbonopsis providencis* of the Cooper.

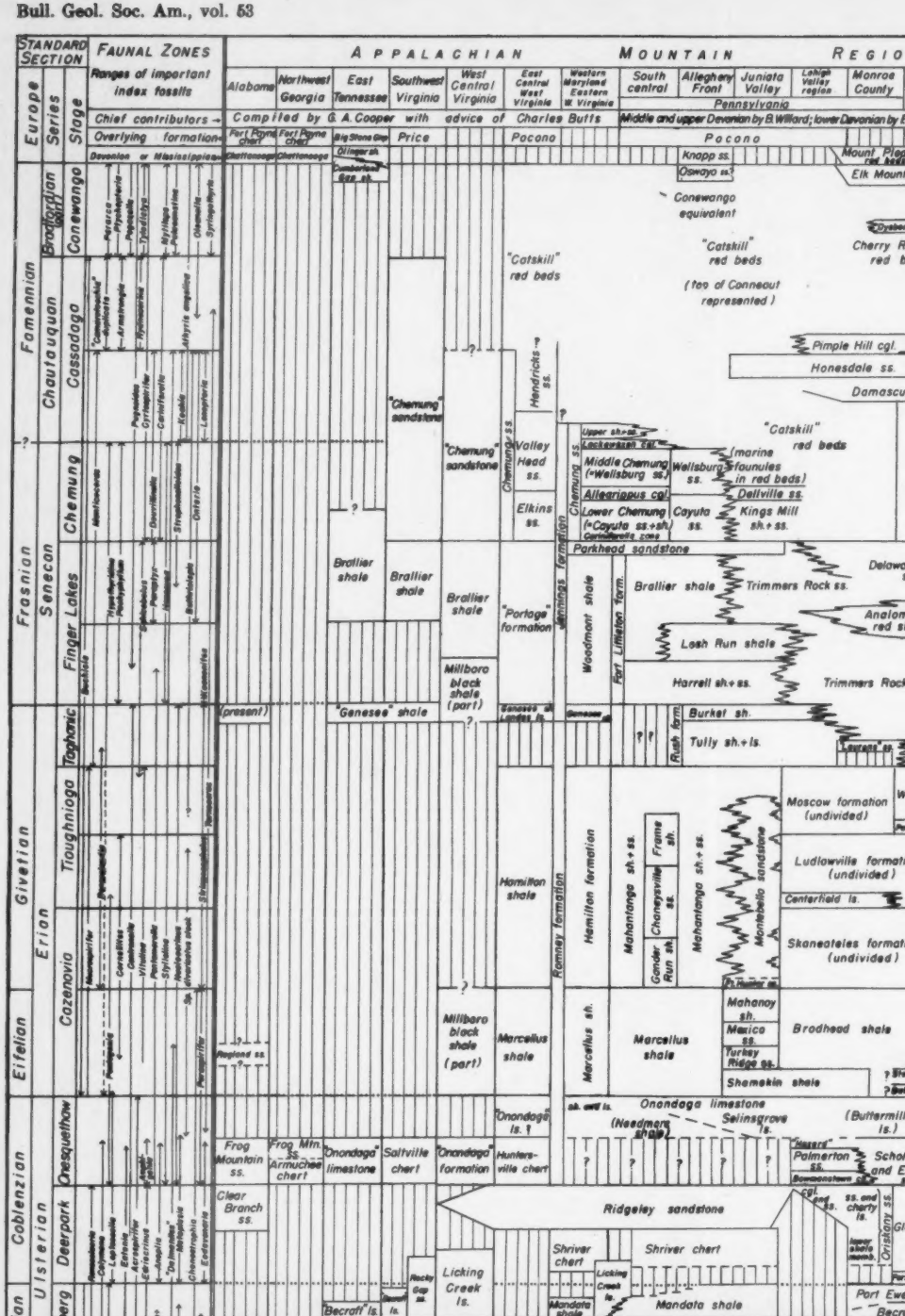
West Range limestone.—Contains *Athyris "angelica,"* rotund *Cyrtospirifer, Pugnoides,* and a fine-ribbed *Camarotoechia* and is placed in the Canadaway.

In the Dutch John Mountain section 40 miles north of Pioche Merriam (1940, p. 39) shows that *Cyrtospirifer* ranges for 1835 feet and that the limestone is divisible into five zones. The two lowest, A and B, contain *Cyrtospirifer* and *Pachyphyllum* and are referred to the Chemung. Zone C, or *Cladopora* zone, follows, and on this is zone D which abounds in brachiopods of the West Range formation and is assigned to the Canadaway group of the Cassadaga stage. A fifth zone (E) is not placed.

Williams Island limestone.—In James Bay region includes upper 8 feet of Abitibi River limestone of Savage and Van Tuyl and 30 feet of drab, soft limestone above it (Kindle, 1924, p. 34). The section is capped by 2 feet of limestone containing *Hypothyridina*. According to Kindle the rock below *Hypothyridina* contains Hamilton fossils. Therefore the part containing these fossils has been placed in the Hamilton, and the *Hypothyridina* bed assigned to the Tully.

Winnepegosis limestone.—*Stringocephalus*-bearing limestone related to the Elm Point and Manitoba limestones. (*See* Manitoba.)




STANDARD SECTION
FAUNAL ZONES
Ranges of important index fossils
APPALACHIAN MOUNTAIN REGIO
Alabama
Northwest Georgia
East Tennessee
Southwest Virginia
West Central Virginia
East Central West Virginia
Western Maryland Eastern W. Virginia
South central
Allegheny Front
Juniata Valley
Lehigh Valley region
Monroe County
Pennsylvania
Chief contributors
Compiled by G. A. Cooper with advice of Charles Butts
Middle and upper Devonian by B. Willard; lower Devonian by E
Overlying formation
Devonian or Mississippian
Europe
Series
Stage
Famennian
Frasnian
Givetian
Eifelian
Coblenzian
Gedinnian
Senecan
Chautauquan
Conewango
Cassadaga
Chemung
Finger Lakes
Genesee
Taghanic
Tioughnioga
Cazenovia
Onesquethaw
Deerpark
Helderberg
Ulsterian
Erian
Bradfordian
Portage
Hamilton
Marcellus shale
Onondaga limestone
Onondaga chert
Onondaga formation
Hunters-ville chert
Frog Mountain ss.
Frog Mtn. ss. Armuchee chert
Clear Branch ss.
Becraft ls.
New Scotland ls.
? New Scotland ls.
Licking Creek ls.
Shriver chert
Ridgeley sandstone
Mandata shale
Coeymans ls.
Healing Springs ss.
Rocky Gap ss.
Oriskany ss.
Port Ewen
Becraft
Stormville
Brallier shale
Millboro black shale (part)
Genesee shale
Harrell sh. + ss.
Trimmers Rock ss.
Burket sh.
Tully sh. + ls.
Moscow formation (undivided)
Ludlowville formation (undivided)
Centerfield ls.
Skaneateles formation (undivided)
Mahantango sh. + ss.
Montebello sandstone
Marcellus sh.
Mahanoy sh.
Mexico ss.
Turkey Ridge ss.
Brodhead shale
Shamokin shale
Selinsgrove ls.
Palmerton ss.
Bossardtown ss.
Schoharie and E
Pimple Hill cgl.
Honesdale ss.
Damascus
Knapp ss.
Oswayo ss.
Elk Mount
Conewango equivalent
"Catskill" red beds
(top of Conneaut represented)
Cherry R
red b
Hendricks ss.
Valley Head ss.
Elkins ss.
Middle Chemung (=Wellsburg ss.)
Wellsburg ss.
(marine faunules in red beds)
Allegrippus cgl.
Dellville ss.
Lower Chemung (=Cayuta ss.+sh.)
Cayuta ss.
Kings Mill sh.+ss.
Parkhead sandstone
Delawa
Jennings formation
Woodmont shale
Fort Littleton form.
Rush form.
Loch Run shale
Brallier shale
Trimmers Rock ss.
Analon
red s
Lewasota ss.
Hamilton formation
Ramsey formation
Chemung ss.
Lockwood Run
Upper sh.+ss.
Underlying formation
Chazy to Silurian
Silurian (Tuscarora)
Silurian (Keyser)
Silurian

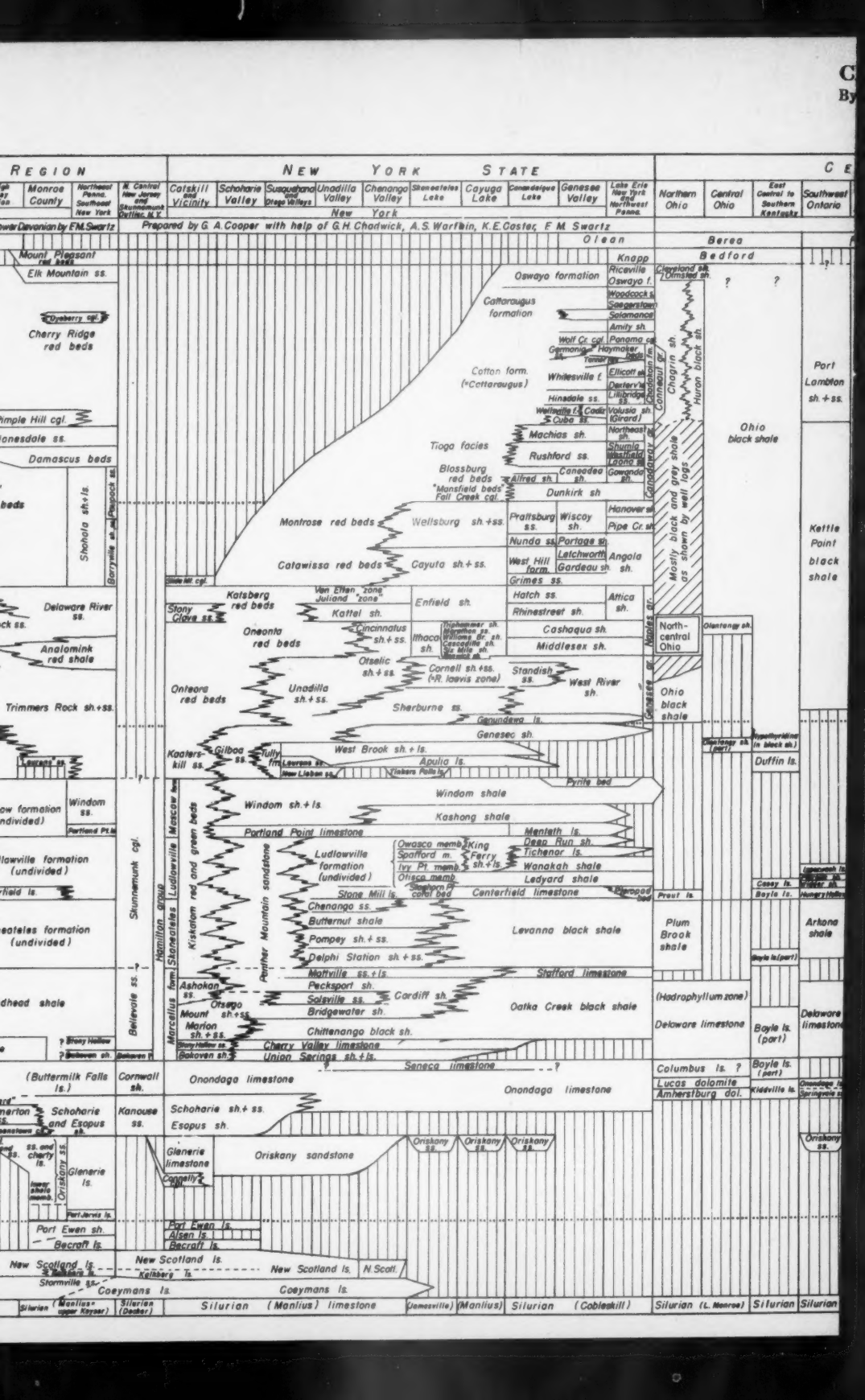
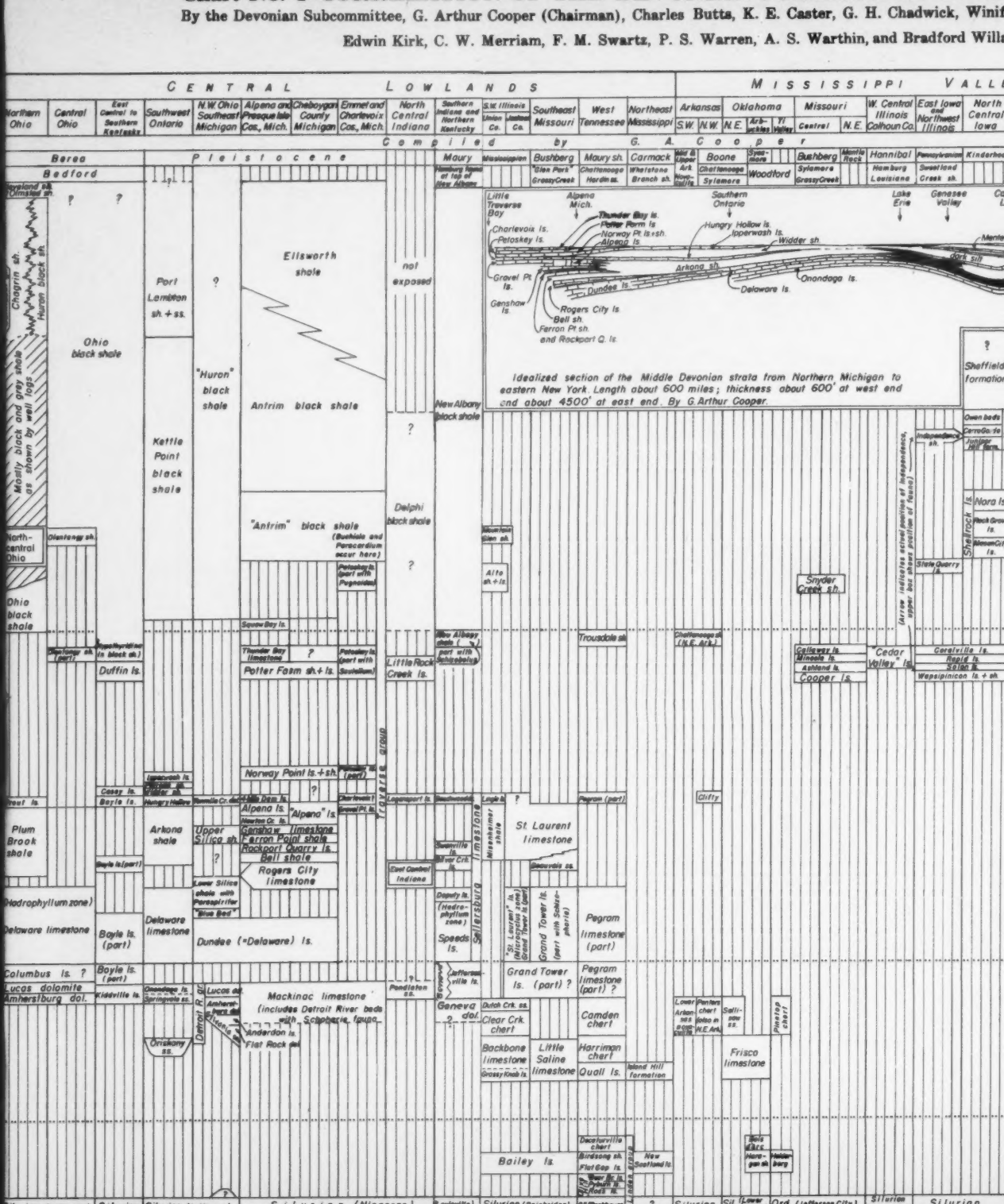

REGION
NEW YORK STATE
Catskill and Vicinity
Schoharie Valley
Unadilla Valley
Chenango Valley
Cayuga Lake
Seneca Lake
Canandaigua Lake
Genesee Valley
Lake Erie New York and Northwest Penna.
Northern Ohio
Central Ohio
East Central to Southern Kentucky
Southwest Ontario
Monroe County
Northeast Penna. Southeast New York
N. Central New Jersey and Skunnemunk Outlier, N.Y.
New York
Prepared by G. A. Cooper with help of G.H. Chadwick, A.S. Warthin, K.E. Caster, F.M. Swartz
Olean
Berea
Bedford
Knapp
Riceville
Oswayo f.
Woodcock s.
Sodersstown
Solamonie
Amity sh.
Panama ss.
Haymaker
Elicott sh.
Dexterville
Libbridge
Valusia sh. (Girard)
Northeast sh.
Shumla
Westfield
Laona ss.
Gowanda sh.
Dunkirk sh
Hanover sh.
Pipe Cr. sh.
Angola sh.
Hatch ss.
Rhinestreet sh.
Attica sh.
Cashaqua sh.
Middlesex sh.
Standish ss.
West River sh.
Sherburne ss.
Genundewa ls.
Genesee sh.
West Brook sh. + ls.
Apulia ls.
Tichenor ls.
Wanakah shale
Ledyard shale
Centerfield limestone
Levanna black shale
Stafford limestone
Cardiff sh.
Oatka Creek black shale
Seneca limestone
Onondaga limestone
Schoharie sh. + ss.
Esopus sh.
Oriskany sandstone
Oriskany ss.
Glenerie limestone
Connelly
Port Ewen sh.
Alsen ls.
Becraft ls.
New Scotland ls.
Kalkberg ls.
Coeymans ls.
Stormville ss.
Silurian (Manlius) limestone
Silurian (Cobleskill)
Silurian (L. Monroe)
Silurian
Mount Pleasant red beds
Elk Mountain ss.
Dryberry cgl.
Cherry Ridge red beds
Pimple Hill cgl.
Jonesdale ss.
Damascus beds
Shohola sh. + ls.
Peacock ss.
Berryville sh.
Delaware River ss.
Analomink red shale
Trimmers Rock sh. + ss.
Lackawack ss.
Windom ss.
Portland Pt. ls.
Skunnemunk cgl.
Bellevue ss.
Stony Hollow
Bakoven sh.
Bakoven ss.
Cornwall sh.
Kanouse ss.
Oriskany ss.
Port Jervis ls.
Manlius (upper Keyser)
Silurian (Decker)
Oswayo formation
Cattaraugus formation
Cotton form. (=Cattaraugus)
Tioga facies
Rushford ss.
Blossburg red beds
"Mansfield beds" Fall Creek cgl.
Montrose red beds
Catawissa red beds
Wellsburg sh. + ss.
Cayuta sh. + ss.
Prattsburg ss.
Wiscoy sh.
Nunda ss.
Portage sh.
West Hill form.
Letchworth sh.
Gardeau sh.
Grimes ss.
Slide Mt. cgl.
Katsberg red beds
Stony Clove ss.
Kattel sh.
Van Ettan zone
Juliand "zone"
Enfield sh.
Oneonta red beds
Cincinnatus sh. + ss.
Ithaca sh.
Triphammer sh.
Wagenhen ss.
Williams Gr. sh.
Cascadilla sh.
Six Mile sh.
Hamlet sh.
Otselic sh. + ss.
Cornell sh. + ss.
(=R. laevis zone)
Onteora red beds
Unadilla sh. + ss.
Kaaterskill ss.
Gilboa ss.
Tully ls.
Lorraine sh.
New Lisbon ss.
Tioga Falls ls.
Pyrite bed
Windom sh. + ls.
Windom shale
Kashong shale
Portland Point limestone
Menteth ls.
Deep Run sh.
Ludlowville formation (undivided)
Owasco memb.
Spafford m.
Ivy Pt. memb.
Otisco memb.
Stephen Pt. coral bed
King Ferry sh. + ls.
Stone Mill ls.
Chenango ss.
Butternut shale
Pompey sh. + ss.
Delphi Station sh. + ss.
Moscow fm.
Ludlowville fm.
Stonetoles fm.
Kirkfarm red and green beds
Panther Mountain sandstone
Hamilton group
Marcellus form.
Mottville ss. + ls.
Pecksport sh.
Solsville ss.
Bridgewater sh.
Ashokan ss.
Otsego Mount sh. + ss.
Marion sh. + ss.
Stony Hollow ss.
Chittenango block sh.
Cherry Valley limestone
Union Springs sh. + ls.
Onondaga limestone
Schoharie and Esopus sh.
Glenerie ls.
Oriskany ss.
Port Ewen ss.
Alsen ls.
Becraft ls.
New Scotland ls.
Kalkberg ls.
Coeymans ls.
Silurian (Manlius) limestone
(Clarksville)
(Manlius)
Silurian (Cobleskill)
Silurian (L. Monroe)
Silurian
Cleveland sh.
Olmsted sh.
Chagrin sh.
Huron black sh.
Connaut gr.
Chadakoin fm.
Canadaway gr.
Genesee gr.
Naples gr.
Mostly black and gray shale as shown by well logs
Ohio black shale
North-central Ohio
Olentangy sh.
Hyattsville sh. (part)
Duffin ls.
Prout ls.
Plum Brook shale
(Hadrophyllum zone)
Delaware limestone
Columbus ls. ?
Lucas dolomite
Amherstburg dol.
Boyle ls. (part)
Kiddville ls.
Casey ls.
Boyle ls.
Hungry Hollow
Boyle ls. (part)
Arkona shale
Delaware limestone
Onondaga ls.
Springvale ss.
Oriskany ss.
Port Lambton sh. + ss.
Kettle Point black shale

Chart No. 4 - CORRELATION OF THE DEVONIAN FORMATIONS OF NO

By the Devonian Subcommittee, G. Arthur Cooper (Chairman), Charles Butts, K. E. Caster, G. H. Chadwick, Winif

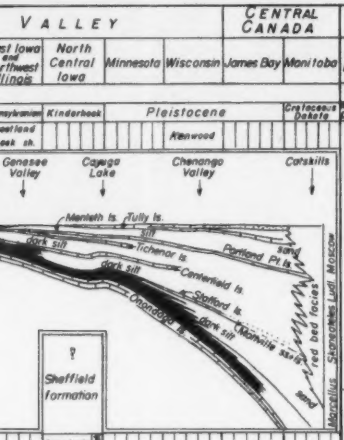
Edwin Kirk, C. W. Merriam, F. M. Swartz, P. S. Warren, A. S. Warthin, and Bradford Will



OF NORTH AMERICA

vick, Winifred Goldring, E. M. Kindle,

dford Willard.



R E G I O N

W E S T E R

Southwest Utah | Gold Hill Utah | Northeast Utah | Northwestern and western Wyoming | Southwest Montana | Northwest Montana | Idaho | Crowsnest Pass Alberta | Banff Alberta | Roche Miette Albert

the help of C. W. Merriam

Prepared by P. S. Warre

Mississippian (Madison)

"Threeforks"

Threeforks shale

Milligan (part)

Exshaw shale

Three forks ls.

Grandview dol.

Minnewanka limestone (upper part)

Sperfel Bear limestone

Lone Butte ls.

Coopers Gate ls.

Glenn Cr. sh.

White Ridge limestone

Darby formation in Western Wyoming

Jefferson limestone

Minnewanka limestone (lower part)

Perdrix shale

Flume limeston

Ghost River formation

Phosphoria Peak ls. (Vinta dist.)

Jefferson limestone

Guilmette ls. (part)

Stringocephalus zone

Guilmette ls. (part)

Simonson dolomite

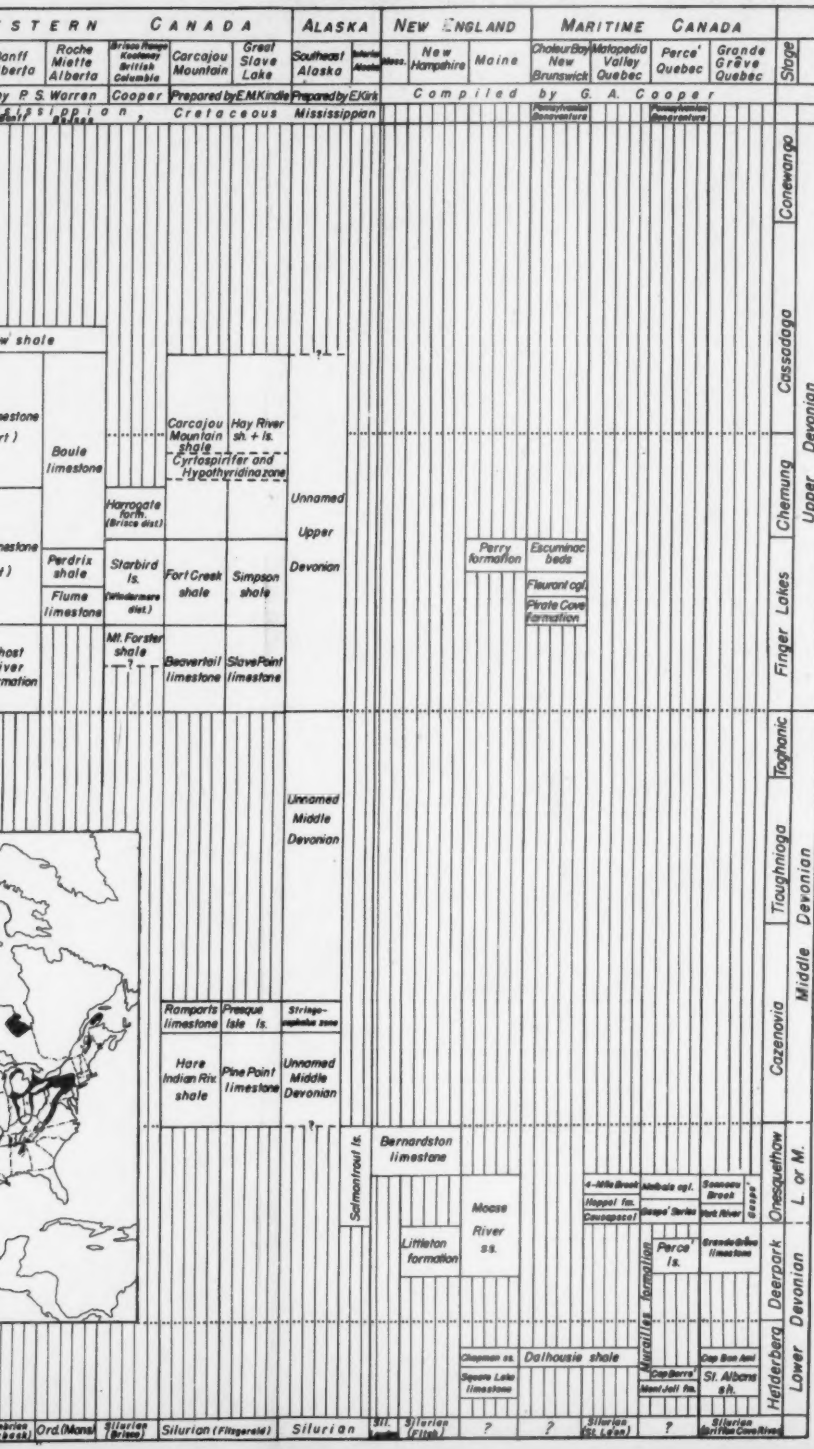
Sevy dolomite

Beartooth Butte limestone

Map of Devonian outcrops.

Red Warrior | Silurian (Lakeltown) | Ordovician (Bighorn) | Upper Cambrian | Silurian (Lakeltown) | ? | Cambrian (Dawbeck) | Ord. (Mons

Prepared under the auspices of the Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, *Chairman*.



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